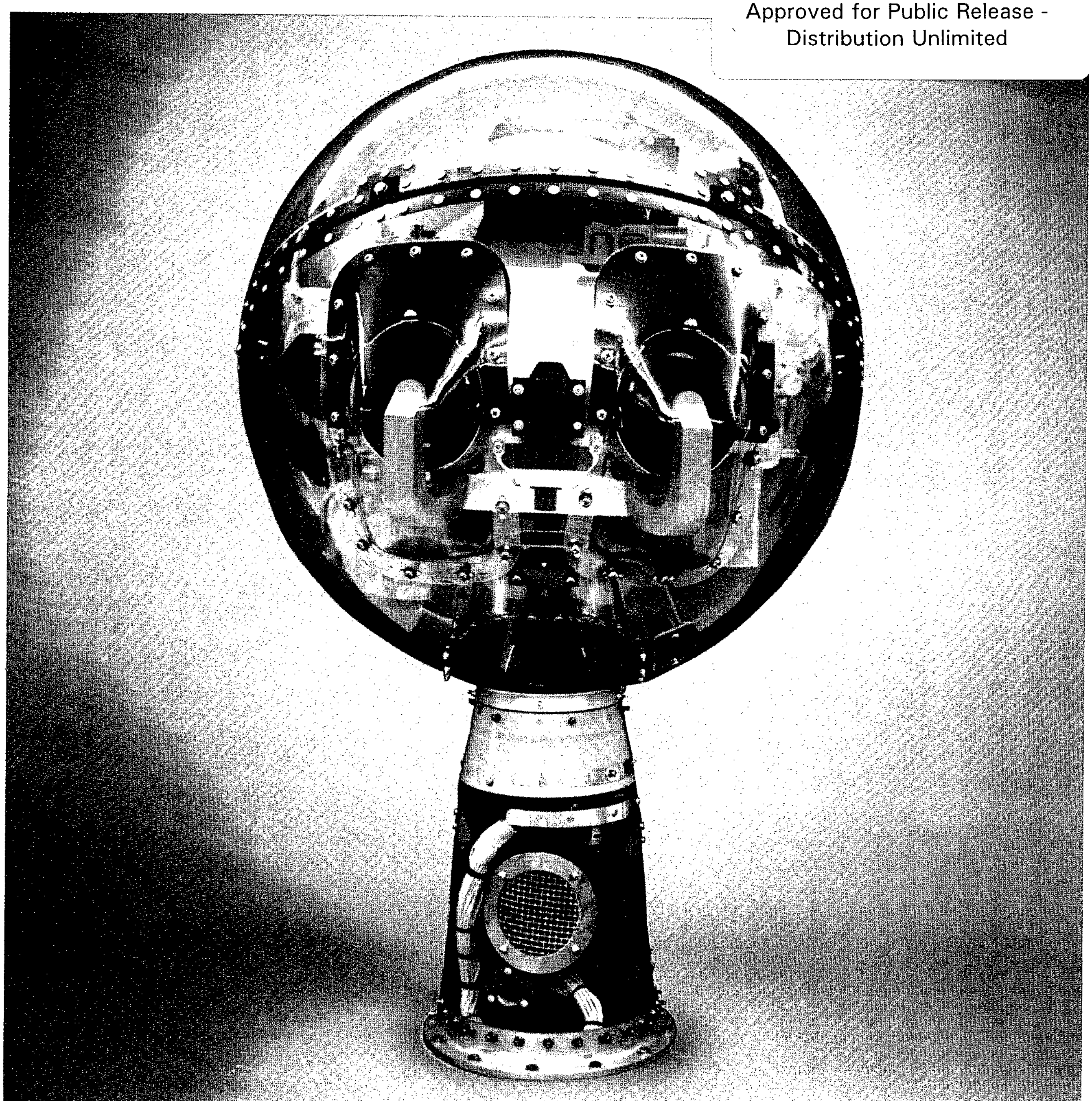
US Army

ManTech Journal

Earlier MT Consideration

Volume 9/Number 4/1984



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Contents

About the Cover:

Model of a prototype of the U.S. Army Aviation Systems Command mass mounted sight (MMS) system used on the AHIP-OH-58D helicopter is shown on the cover of this issue of the U.S. Army ManTech Journal. The sensor support structure (S^3) of the MMS, which currently is made of beryllium, is the object of an AVSCOM mantech task in which advanced composites are being used to make the S^3 more producible and less costly to manufacture. This task will be the subject of a future journal article.

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Comments by the Editor

The year 1985 will witness continuing change in manufacturing technology developments, both within the services and in industry. The recently completed 16th Annual Conference of the Department of Defense Manufacturing Technology Advisory Group (MTAG) presented several perspectives on these impending changes, featuring special presentations on the factory of today, the factory of tomorrow, and the DoD industrial modernization incentives program. These outlined some of the changes modern production practices are undergoing—changes that are being addressed by several different organizations, both government and private.

RAYMOND L. FARROW

A recent newspaper account by United Press International briefly summarized a new report on the factory of tomorrow that was the result of a National Science Foundation funded study by the Purdue University Industrial Engineering Department; we have contacted one of the principal authors, and plan to carry an article on the findings of the study in the next issue of the ManTech Journal. We think our readers will find the projections presented in this report of extreme interest.

A significant aspect of these findings is the predicted effect of future manufacturing procedures on the white collar work force. This projection would indicate that the Army certainly is on the right track with its current thrust to extend the capabilities of its manufacturing engineers through an active program of continuing additional training. Greater demands on the individual talents of engineers in manufacturing will be the norm as we proceed toward the next century.

The Army program was the main topic in the last Army ManTech Journal of an editorial by Frederick Michel, Deputy Chief of Staff for the U.S. Army Manufacturing Technology Program at the Army Materiel Command Headquarters. As stated therein, the tremendous expanse of the Army production base presents an enormous challenge for Army production managers, who are faced with the demand for modernizing facilities while simultaneously initiating cost efficiencies.

This issue of the U.S. Army ManTech Journal contains a wide range of manufacturing technology articles from several DARCOM commands; also a large number of brief reports on the status of ongoing Army mantech projects. These latter briefs complete the most comprehensive coverage our publication has given in one year of current projects—a practice that we plan to continue into 1985 and beyond as new projects come on stream to replace those being completed each year.

The Tank-Automotive R&D Command furnished us with four interesting articles from their own newspaper, The T-A News, which were prepared by one of their writer-editors for public relations uses. We think our readers will find these short reports interesting and informative. They include discourses on flexible manufacturing systems, chemical agent resistant paints, laser welding systems, and simulated vehicle testing.

The article on replacement of aluminum extrusions in helicopter flooring by composite materials points up the limited application of a newly developed technology due to production factors. The new technique is cost effective in one application while it is not so in an application that involves further complexities of fabrication.

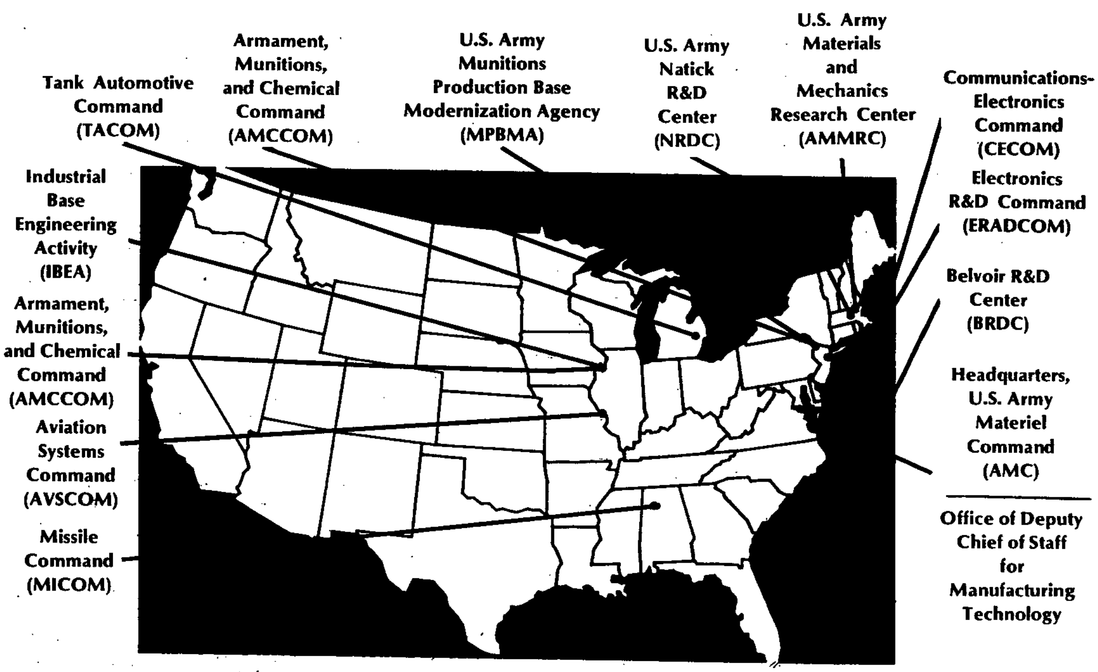
A mantech project funded by the Electronics R&D Command has made possible the production of larger boules of Nd:YAG material at lower cost, as outlined in the article on page 11. This achievement can be expected to have a profound effect on military applications of these lasers in the future.

Another ERADCOM project that will impact future military applications of electro-optics is described in the article on epitaxial growth of gallium arsenide phosphides. This project reflects the foresight of the Army's Night Vision & Electro-Optics Laboratory in anticipating a potential problem of supply for common module arrays used in forward looking infrared devices. The cessation of production by the commercial supplier necessitated the development of a capability by the government to supply its own materials meeting modern performance requirements.

The article on semi-additive printed wiring was based on a paper presented by U.S. Army Missile Command engineer Robert Brown in conjunction with General Dynamics engineer Robert Haner at the 16th National Technical Conference of SAMPE in October of this year. The paper presents an outstanding discussion of the technicalities of this type of fabrication and, through its comprehensiveness, should provide some very useful information to our readers.

The article on thin film transistor displays on page 42 provides new directions for further development of this promising technology, which is not entirely practical at the present time due to inherent surface morphology problems but which promises to have wide application in the future.

AMC Manufacturing Methods and Technology Community



A Cost Tradeoff?

Composites for Aluminum Extrusions

FREDRICK H. REED is a group leader in the Production Technology Branch, Development and Engineering Directorate, U.S. Army Aviation Research and Development Command, with responsibilities for Producibility Engineering and Planning (PEP), Military Adaptation of Commercial Items (MACI), and Manufacturing Technology. He is a graduate in Electrical Engineering of Howard University, Washington, D.C. (1969) and the DARCOM Intern Training Center in Industrial/Production Design Engineering (1971). Since joining the federal service, he has held various positions in the Army Aviation Production Base Support Program, including AVSCOM Facilities Coordinator and NC CAD/CAM Coordinator for AVRADCOM. Mr. Reed is a member of the Institute of Electrical and Electronic Engineers and the American Helicopter Society.

Complex solid laminate tee section pultrusions when used as chord or cap members in adhesively bonded beam assemblies have been proven cost effective, compared to the installed cost of standard aluminum extrusions. However, pultruded honeycomb sandwich panels are not cost effective when compared to hand layups and autoclave or press cured panels, where extensive operations are required to convert the pultruded sandwich assemblies into more complex beam shear web components.

These were the findings of an MM&T project on the use of pultrusions in the manufacture of medium-lift helicopter flooring, which was done for the U.S. Army Aviation Systems Command by Boeing Vertol.

The Boeing Vertol Company had developed an all composite cargo floor and underfloor support beams for its commercial helicopters. These components were fabricated by conventional hand layup and autoclave cure techniques.

The intent of this program was to combine these two technologies and apply them to the design, construction, and field evaluation of composite flooring and underfloor structure in the new U.S. Army CH-47D Chinook helicopter (Figure 1).

The program was divided into three phases with funds available for Phases I and II only. Authorization to proceed with Phase II was predicated on the results obtained in Phase I. A further goal of the program was to retrofit the floor components developed into an Army helicopter for field service evaluation. Since the main cargo area floor beams are an integral part of the CH-47 fuselage structure, replacement of the metal floor beams is a complex operation. Accordingly, it was decided to select a main beam in the CH-47 cargo ramp shown in Figure 1. The entire ramp structure is easily removed from the helicopter, and new units are in production, thus the composite components can easily be installed during fabrication and the assembled ramp installed on a service aircraft. Accordingly, a main cargo ramp beam subjected to high floor loads and emergency water landing loads was selected for the test item. The beam had a straight aluminum extruded upper tee cap and a stretch formed alumi-

NOTE: This manufacturing technology project that was conducted by Boeing Vertol was funded by the U.S. Army Aviation Systems Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The AVSCOM Point of Contact for more information is Fred Reed, (314) 263-3079.

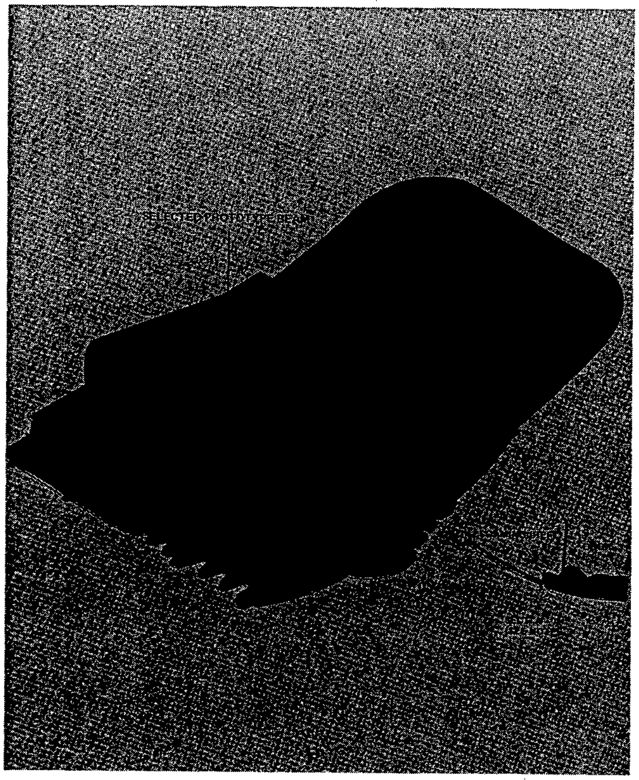


Figure 1

num lower tee cap containing a moderate fuselage contour which was considered to be post formable when fabricated from a less than fully cured composite pultrusion.

Since the beam was to be retrofitted into a production ramp, all end fittings, fastener locations, cable pass-through openings, etc., had to be compatible with the existing metal structure attached to the beam. This requirement introduced a number of design complexities, many of which could be eliminated in an all composite cargo ramp redesign. The demonstration ramp configuration beam is shown in Figure 2 and the conceptual floor panel retrofit in Figure 3.

Cargo Floor Beam Design

A preliminary design of the composite beam was made, incorporating the necessary existing metal fittings, cutouts and high density compression resistant fastener areas required for retrofit into a production ramp. In

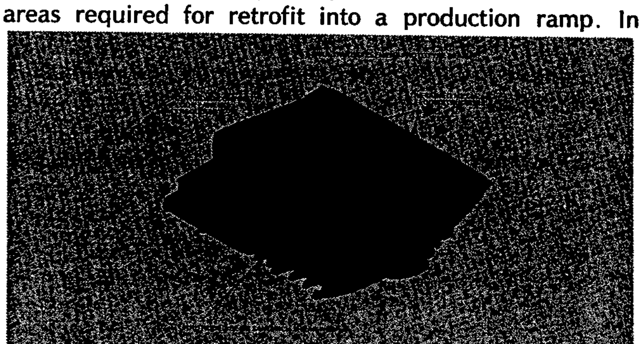


Figure 2

addition, the beam was configured to accommodate the higher water landing loads expected in the CH-47D. These loads may result from the higher gross weight and rate of descent specified for the D model.

Graphite and Kevlar materials, qualified to Boeing material specifications and compatible with the existing operational pultrusion equipment, were selected. The beam structural design criteria included frame bending and shear design loads induced by water landing and vehicle wheel loads on the ramp treadways. Local design loads caused by the water landing condition were also defined. Those loads are described in Figure 4.

After the basic beam configuration, airframe loads and materials design properties were defined, the main beam components, upper cap, lower cap, and shear web were configured and basic materials and assembly processes stipulated. The design details are shown in Figures 5 through 8.

Figure 3

The lower beam cap, due to its twisted and curved contour required to match the fuselage skin contour, was originally designed for hand layup and autoclave cure (shown in Figure 9). However, later work by the pultrusion development group had shown that post-forming was possible in the final assembly beam bond cure process. As a result, in order to make greater use of pultrusions, beam cap pultrusion dies were redesigned to accommodate the larger lower cap dimensions. The smaller upper cap would then be machined out of the common pultrusion cap produced. A structural analysis of the beam was conducted in order to access margin of safety in the composite beam design.

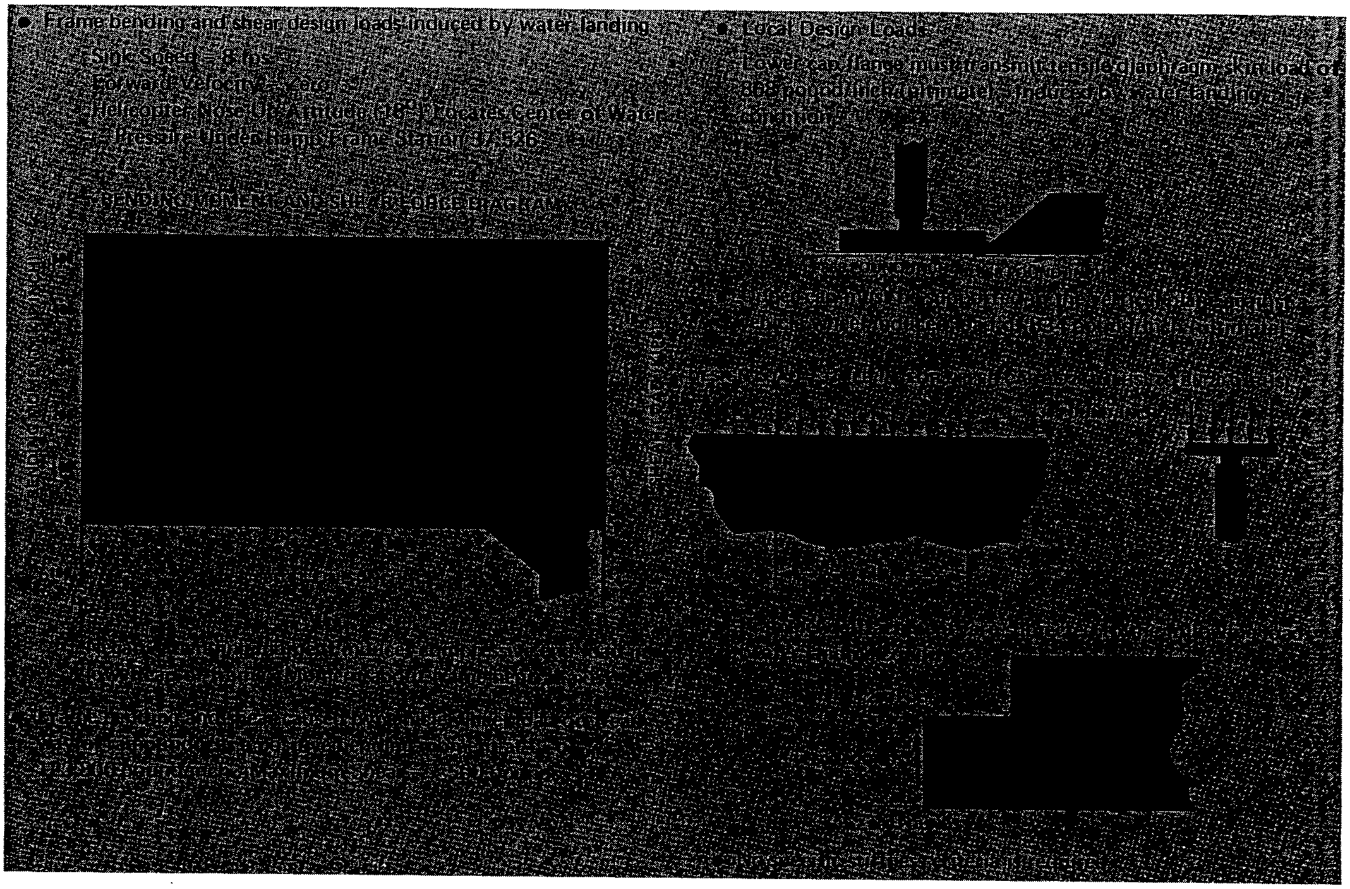


Figure 4

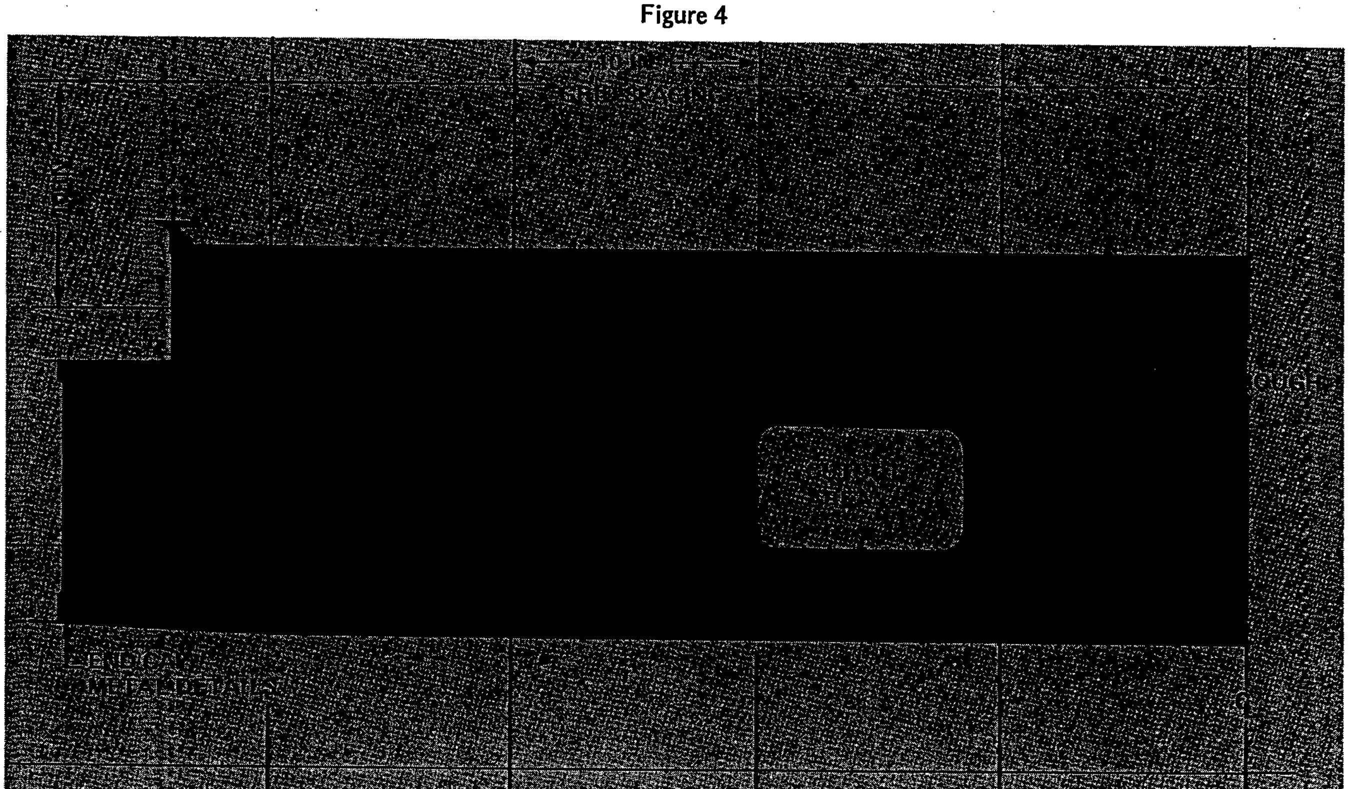


Figure 5

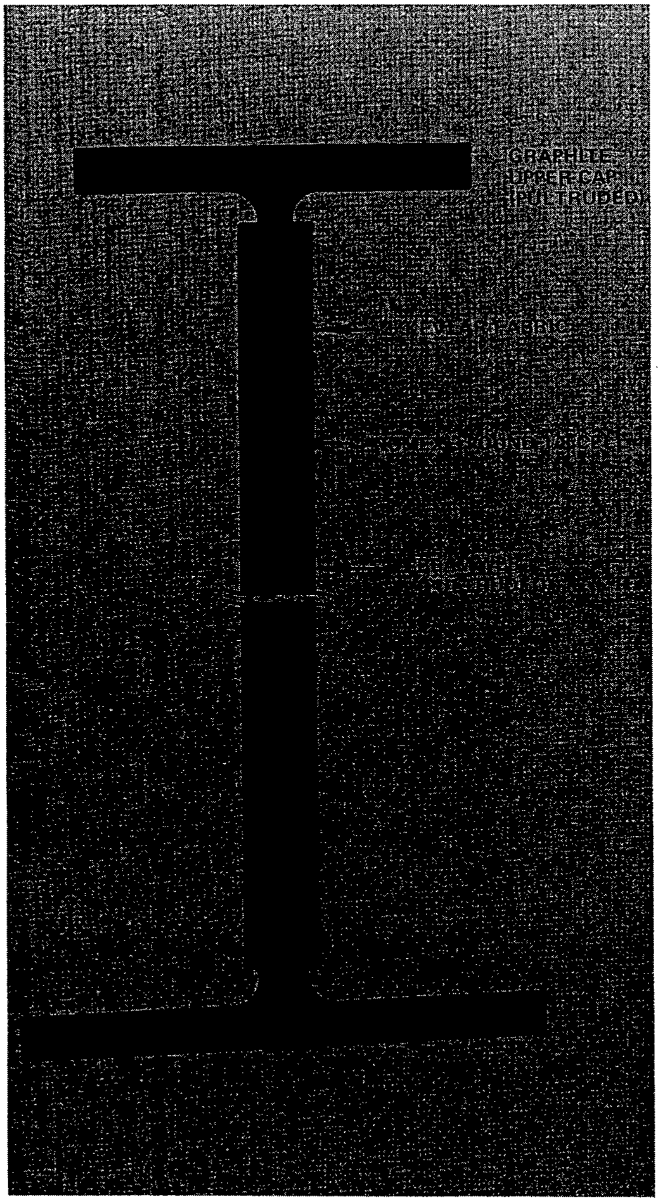


Figure 6

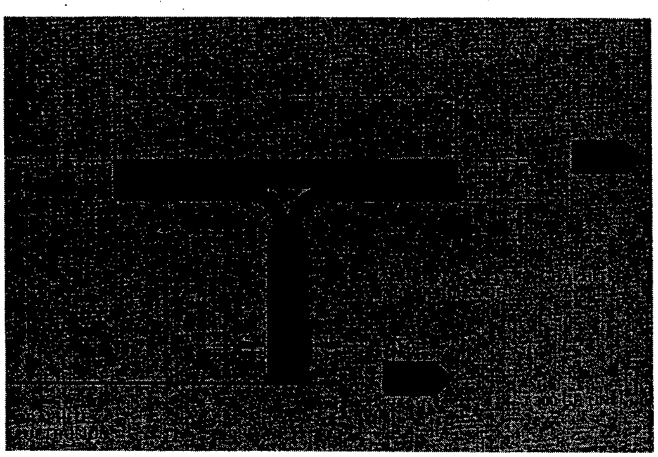


Figure 7

Fabrication Techniques

The program definition required the use of pultruded beam components and floor components, with significant emphasis on the design and utilization of the newly developed sandwich panel pultrusion process.

Since the completed underfloor beam had to be geometrically and functionally interchangeable with the existing metal underfloor beam, a fabrication plan was developed which made use of the existing beam final assembly bonding tools. The pultrusion fabricated beam tee caps and shear web panels were to be cut to final dimensions prior to assembly. The shear web doublers, local hole reinforcements, etc. were to be precut. The honeycomb core around the shear web periphery was to be slotted to accept the cap vertical legs and the metal end fittings. All details were to be coated with film adhesive and the entire assembly adhesively bonded in the production beam assembly tooling.

In preparation for production of the beam components, samples of the tee caps and pultruded sandwich panels previously fabricated were evaluated. Significant details

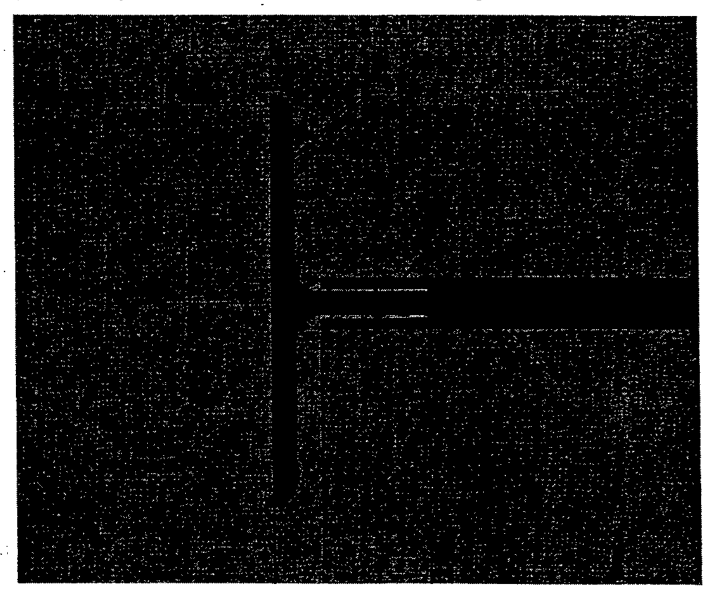


Figure 8

of the equipment, tooling, and component evaluations related to the pultrusion fabrication operations are described in subsequent sections.

Pultruded Beam Tee Caps

Tee cap or beam chord elements were formed and cured with this equipment; they were found to have structural

properties meeting or exceeding those developed by sections fabricated by layup and autoclave cure techniques.

Later work demonstrated that partially cured sections could be bent and postformed during a subsequent cure operation, and it was this concept that was selected for fabrication of the CH-47 lower beam cap element.

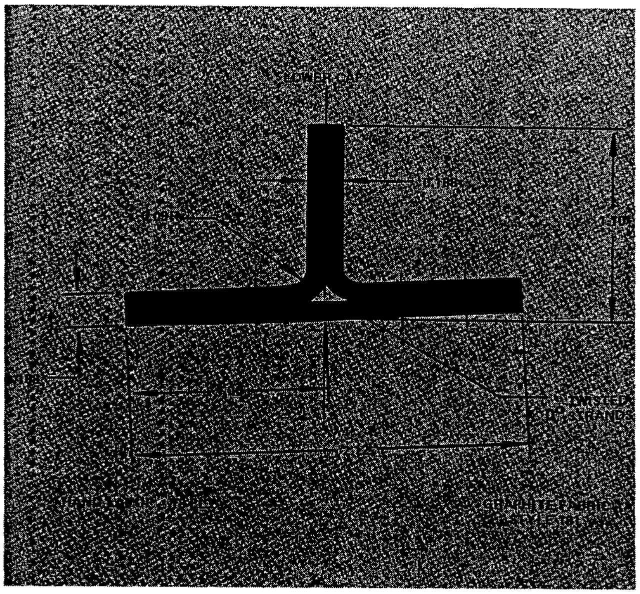


Figure 9

Pultruded Beam Shear Web

The machine developed by Boeing was used to produce 60-inch wide glass fabric faced nomex honeycomb construction. At the beginning of this contract effort, the machine had demonstrated that panels could be made in a continuous process and cut to desired length by means of a flying cut off mechanism. The development analysis had reached the following conclusions:

- Sandwich panels suitable for use in airframe structure can be made in continuous lengths by pultrusion.

- Nomex core must be dried immediately before application of the uncured composite skins when making sandwich panels by pultrusion to assure maximum properties.

- Skins formed of linear fibers cross-plied into a prepreg tape provide a means of self-adhesion to the core by use of a high resin content on the ply next to the core and a lower resin content in the structural face plies.

- Current specifications for sandwich panels can be met by using the pultrusion process.

- Panel thickness varies with the thickness of the core as well as the spacing and pressure on the platens of the pultrusion machine.

One of the principle parameters used in the evaluation of honeycomb panel structural integrity is a skin peel test. A simple skin peel (climbing drum test) test fixture was designed using a torque wrench to quickly evaluate the peel strength of the pultruded panels.

Resin gel time, flow, volatile content, and weight percentage in the prepreg material used for the skin plies could be varied within considerable limits with little effect on panel peel strength when a film adhesive was used as the bond medium. Typical prepreg variations were encountered in the development of panels having adequate structural properties. The Kevlar and graphite prepreg selected for the beam shear web panels to be used in this program was to be evaluated in the same manner in order to set the pultrusion machine process parameters.

Factors Precluding Completion

The program was not completed due to the following factors:

(1) The proposed honeycomb sandwich floor design for the CH-47D was changed to an extruded aluminum stiffened plate due to requirements for maximum cargo area volume, which would have been reduced due to the increased thickness of a sandwich panel floor.

(2) Economic analysis of the continuous sandwich panel pultruder operations, combined with the qualification of additional commercial firms to produce sandwich panels, resulted in negligible cost savings achievable by the continued development and in-house operation of the equipment, and the in-house operation of the sandwich pultruder was discontinued.

(3) After the above decision was made, several commercial pultrusion firms were contacted in an effort to demonstrate sandwich pultrusion techniques on panels of sufficient width to fabricate the underfloor

beam webs. The cost of the large quantity of material, approximately 300 lineal feet, and the requirement to vertically stitch the plies together to insure suitable fiber alignment and location exceeded the program materials budget.

(4) The additional operations required to convert a sandwich panel blank to a more complex underfloor composite beam shear web (cutouts, doublers, stabilized core areas, etc.) forced the assembly back into the detail layup shop and the autoclaves. The resulting costs rendered the approach impractical for the particular design selected for this program.

Economic Analysis

Although the composite underfloor beams were not constructed in this program, sufficient pultrusion equipment operation was performed and related cost data developed to form the basis for a comparative cost estimate between an all aluminum beam and an all composite pultruded shear web and cap replacement beam assembly.

The developed pultrusion cost data, current procurement costs for aluminum extrusions, honeycomb core and sheet aluminum skins, and nomex core, graphite and Kevlar prepreg materials were used in the economic analysis. In addition, the industrial engineering time standards developed for the fabrication and assembly of the metal beam caps and sandwich shear web were used to develop the costs of the metal beam components which were to be replaced with pultruded composite beam elements. Those items which were common to both beam designs—end fittings, fasteners, angles, clips, and brackets—were not included in the cost comparison. In addition, the costs for an all composite beam fabricated by hand layup techniques were estimated.

No manufacturing cost or structural weight advantage was found for the pultruded beam. The completed beam caps manufactured from pultruded graphite stock were actually lower in final cost than the same components fabricated from standard aluminum extrusions. However, the costs associated with the conversion of a simple pultruded sandwich panel into the more complex beam shear web configuration more than offset the savings attainable in the pultruded tee caps. It should be noted, however, that the composite beam was designed for more severe water landing impact than that required of the metal beam.

Table 1 shows the comparison in final assembly/adhesive bond costs for the metal and composite beam elements.

Detail Operation	Metal Conventional	Composite Automated	Composite Hand Layup
Clean and chem process metal details	312	–	–
Clean and process tool BAJ	30	30	30
Apply adhesive to detail parts	270	170	200
NC trim composite panel	–	148.8	–
Fixture route panel edges	–	195.0	
Install potting compound	20	192.0	120
Cut doubler patterns	60	126.0	90
Install doublers	30	30	30
Install details and lower skin	30	–	30
Assemble core details and install	15	–	15
Install caps and end fittings	150	150	150
Close tool	27	27	27
Vacuum bag	60	60	60
Autoclave cure	98.8	98.8	98.8
Paint and stencil PN	45	45	45
Wrap and store	12	12	12
	$\frac{1{,}159.8}{60}$ = 19.33 Hours	$\frac{1{,}284.6}{60}$ = 21.41 Hours	$\frac{907.8}{60}$ = 15.13 Hours

Table 1

The Emphasis is on Flexibility

Automated Manufacture for Low Volume Production

By George Taylor
U.S. Army Tank—Automotive Command

TACOM and Draper Labs Inc. have developed computer-aided design procedures that make practical the automated manufacture of low-volume-production items such as military vehicles and components.

The effort is part of DOD's Manufacturing Methods and Technology (MM&T) program to improve military equipment and reduce production cost by using advanced technology.

With the rapid growth in automation technology, the automobile industry and other high-volume manufacturers have come to rely increasingly on automation for machining and assembling parts and performing other routine tasks.

The results of this trend have been reduced labor costs and, in many instances, improved product quality.

Until recently, however, automation has been limited to high-volume production because it was not economically practical to buy expensive automated equipment that could only make large quantities of one specific item.

But advances in the state-of-the-art of automated manufacturing technology now permit the development of flexible manufacturing systems.

Suitable for Small Batches

These consist of arrangements of computer-controlled machine tools and material-handling equipment capable of producing small quantities of a number of similar parts, rather than a large quantity of one part.

According to David Pyrce, TACOM R&D Center MM&T project engineer, this flexibility has great potential in military vehicle manufacturing, where the production volume for a given vehicle may be several hundred to several thousand units. This is too small a quantity for traditional "Detroit Style" automation.

"If you look at what goes into a vehicle," Pyrce noted, "you can find parts which, though not identical, are similar. In a tank, for example, the housings for the various fire-control systems are similar aluminum castings.

"By designing automated machines capable of making enough similar parts, we can get sufficient production volume to make automation feasible."

Complex Automated Equipment

Flexible manufacturing systems are far more complex than conventional automated equipment and would be extremely costly to develop by standard methods. Pyrce said, however, that the computer-aided design approach makes it possible to create and optimize system designs at sharply reduced cost.

In computer-aided design, an engineer creates and modifies design models by entering graphic or mathematical information into a computer. Once created, the model is permanently stored in a data base within the computer and is used in various design and analysis operations.

"The big cost advantage to computer-aided design," said Pyrce, "is that you can literally design a system on a computer and run it to see if it will work, without having to buy expensive machine tools."

TACOM's involvement in computer-aided designing of flexible manufacturing systems began in 1979, when the command awarded Draper, a pioneer in flexible manufacturing technology, the first of five contracts for a two-phase, five-year effort.

In the first phase, Draper developed a family of computer programs that simulate flexible manufacturing and a methodological approach for using the programs to design a system. This effort included the publication of a five-volume methodology handbook for manufacturers.

NOTE: This manufacturing technology project was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The TACOM Point of Contact for more information is Don Cargo, (313) 574-8709.

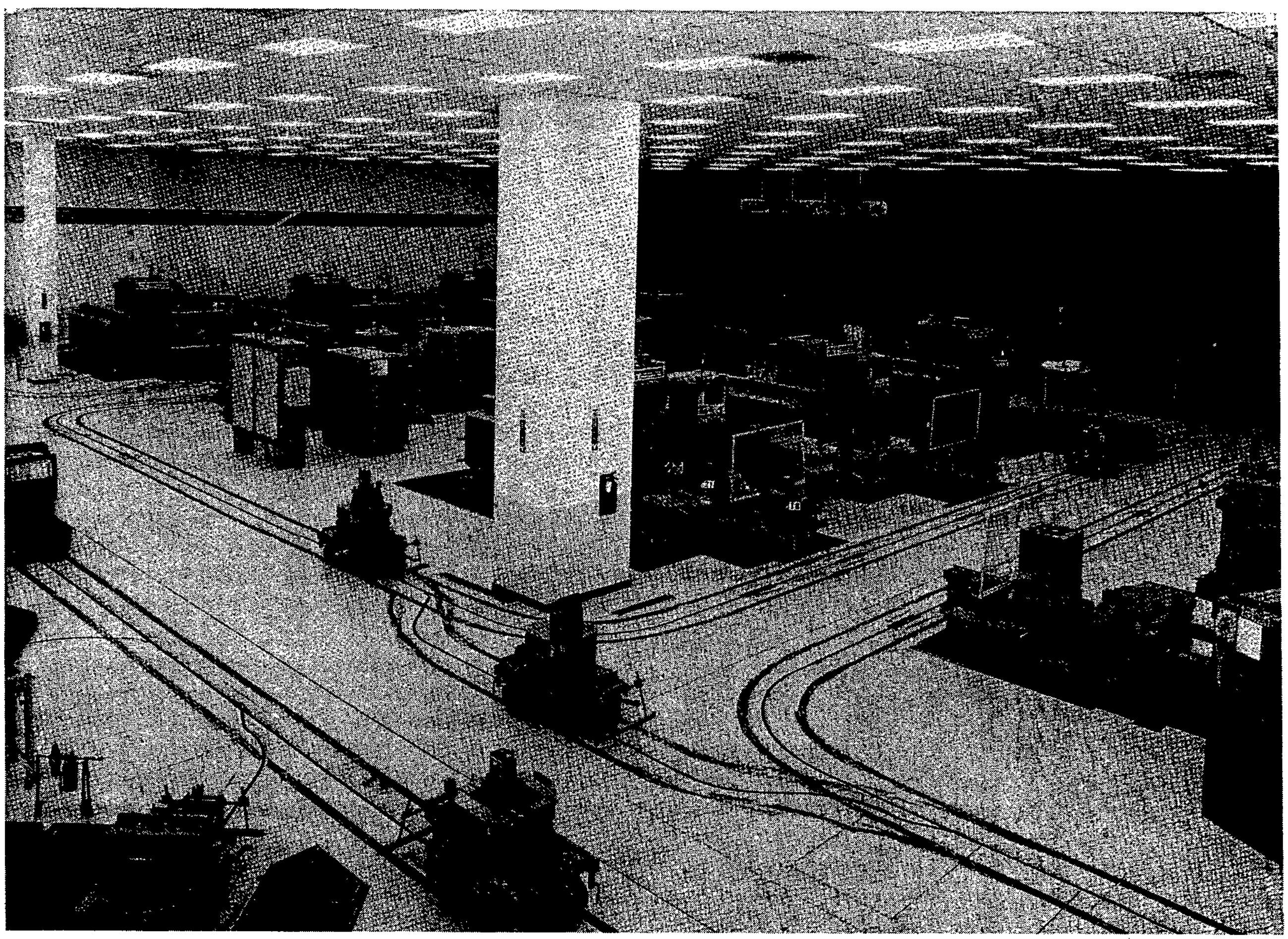
In the second phase, Draper assisted four major Army suppliers in using the programs to design flexible manufacturing systems for production facilities—three of which have decided to buy equipment.

Two Systems Operational

To date, two complete systems have been designed and installed. One of these is at an FMC plant in South Carolina that is soon to begin production of Bradley vehicle suspension components.

The other is located at a Hughes Aircraft plant in California that makes M1-series tank fire-control system housings. Also, work is underway to develop a flexible manufacturing system for use at Rock Island Arsenal, a major supplier of gun components.

Pyrce said that once a system has been designed, the computer programs can serve other purposes, such as scheduling, process planning, determining batch quantities for the parts being manufactured, and mapping contingency plans in the event that a machine tool should fail.



HUGHES AIRCRAFT'S FLEXIBLE MANUFACTURING SYSTEM FOR PRODUCTION OF M1 FIRE CONTROL SYSTEM HOUSINGS. IN OPERATION, THE AUTOMATED CARTS TRANSPORT EACH PART AND ITS FIXTURE FROM ONE MACHINE TOOL CELL TO ANOTHER.

New Growth Process Increases Size

Larger Laser Rods Produced

by

Albert Pinto
U. S. Army Night Vision and Electro-Optics Laboratory

Large single crystals of neodymium doped yttrium aluminum garnet (Nd:YAG) required for future military program applications of optically pumped solid state lasers are now possible. From its discovery in 1964 until the present time, the most expedient method of obtaining such crystals of laser quality has been by means of the Czochralski growth procedure. In current production practice, this method consists of seeding and pulling a crystal from a melt contained in an iridium crucible. The crucible is heated by means of kHz radio frequency induced currents. While the process is a good one it has remained virtually unchanged except for improvements in diameter control systems.

Under a U.S. Army Electronics R&D Command program, the Airtron Division of Litton Industries, Inc. developed a production process which yielded boules of 30-38 mm diameter. For nearly ten years this process has remained the same and few workers attempted any improvement. In the period 1976-77 an increased demand for laser rods engendered an examination of procedures to increase yields. A concurrent objective was the lowering or stabilization of growth costs during a period of high inflation. The principal contributions toward the cost of a laser rod are iridium, electrical power, materials, and labor. Thus, any process which limits or eliminates any of these would be beneficial. During the natural evolution of material growth technology, the trend has been to grow larger crystals. A valid question often has been asked: why not grow larger boules of Nd:YAG?

Three Methods Possible

The justification for larger boules of Nd:YAG is based on the need for greater yields of high quality material at lower costs. This can be accomplished theoretically by the following approaches:

(1) Grow crystals at current production diameters and maintain quality.

NOTE: This manufacturing technology project that was conducted by Airtron Division of Litton Industries for the U.S. Army Night Vision and Electro-Optics Laboratories, was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The ERADCOM Point of Contact for more information is Bob Moore, (202) 394-3812.

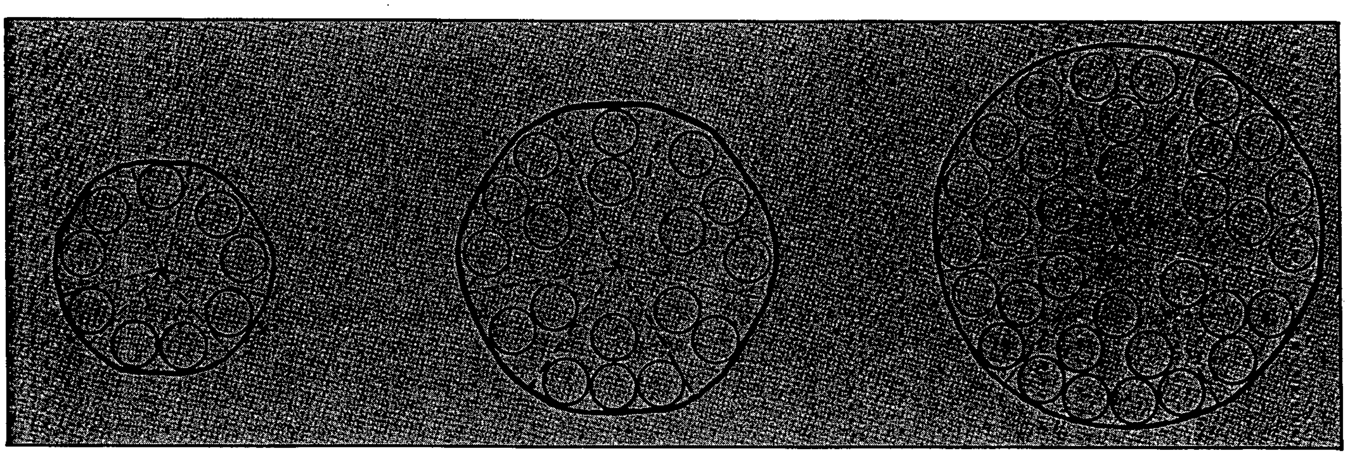
(2) Grow larger diameter cyrstals at the same length and quality.

(3) Improve the optical quality of boules by maintaining the melt composition fixed. This could occur in combination with any advance made in (1) and/or (2).

If the first course is chosen, the growth rate still remains fixed and not much is gained. This is complicated further by the Nd level in the crystal which constantly increases and eventually causes high strain or exceeds the laser rod concentration specification. If the third course is followed, a substantial improvement results, but the time frame for realizing such an effort is certainly several years. Thus, the most promising alternative is the second approach— to grow larger diameter crystals. An increase in diameter to about 50 mm would almost double the rod yield from a boule and seems to be within capabilities based on recent experiments.

Nd:YAG Growth Complicated

Early experiments were begun at Airtron in 1976, and by 1978 a few 50 mm boules were grown with moderate success. These results led to an initiation of the present program to refine the technique for production purposes. The increase of boule diameter of any Czochralski grown crystal is a formidable task. Good methods have been developed for silicon, GGG, and sapphire over a period of years. The degree of difficulty is associated closely with the operating temperatures, number of chemical components, and factors which govern melt behavior. Nd:YAG growth is complicated by a melting point of 1975 C, a three component system, low distribution coefficient (0.18) for Nd, faceting phenomena, and high melt thermal convection. In addition, the growth rate of Nd:YAG from the melt is a rather low 0.5 mm/hr. This places an extremely high demand on the temperature control system. Fluctuations of 10-20 C cannot be tolerated during the entire growth cycle of 2-3 weeks. At the present time, there is no known method to increase growth rate without some sacrifice in quality. Hence, for any planned increase of boule diameter, all the usual problems are not only present but also aggravated. In spite of inherent difficulties with Nd:YAG, it is safer to follow the Czochralski growth route rather than an entirely different procedure. In order to place the objectives of growth in perspective, it is recalled that a popular size of laser rod required in large quantities is the (4.3 x 43) mm cylindrical type. A boule diameter increase from 35 mm at present to 50 mm will almost double the rod yield from a boule. Figure 1 shows a typical boule diameter at each chronological stage of growth development. It also records the number of laser rods of a (4.3 x 43) mm size that can be extracted from such a diameter. Notice that in Figure 1c an increase of only 5-6 mm in the diameter nearly doubles the rod yield from that of Figure 1b, which is current production. Of course, this increase needs to be done at no sacrifice of quality or growth time.



(a) 1967-1972 27 mm dia **(b) 1972-1978 38 mm dia** **(c) 1979 50 mm dia**

Figure 1

Basic Process Used

The basic approach utilized to achieve good quality growth has been to adjust the crucible position within the coil as a means of varying the radial temperature gradient in the melt. It is not clear what the correct gradient should be with the type of growth station design employed. However, previous growth results indicate that a steeper radial gradient is required based on the severity of crystalline defects which have appeared prior to the crystal reaching final diameter. In all growth experiments the radial temperature gradient has been 25-30 C per centimeter. This is substantially lower than the existing gradient in production growth stations, and it has been a difficult parameter to control.

A conceptual view of the basic crystal growth station is presented in Figure 2. A 4.5-inch-diameter and 4.5-inch-high iridium crucible with cover (A) is supported by concentric zirconia tubes (B). This arrangement is surrounded by zirconia grain insulation (C), which is enclosed by a quartz glass tube (D). Power is applied to the crucible by means of an rf coil constructed from circular copper tubing (E). The area above the crucible into which the crystal is pulled is insulated by means of an alumina tube (F) and an alumina cover (G).

To provide a situation for experimental growth similar to that existing in the production growth of smaller diameter crystals, the crucible size has been optimized at a 4.5 inch diameter and 4.5 inch height. This ensures that for a given length of crystal the neodymium dopant concentration typifies that of production crystals and permits the duplication of crystal growth rate. The charge for a crucible of this size capacity is approximately 4300 grams. The expected weight of the pulled crystal is about 1 kg, so no more than 20-25 percent of the melt is removed.

Oxides used for experimental work are obtained from supplies used in the production growth area. These are readily available from commercial vendors at grades of 5-9's and 6-9's purity. In the case of the yttrium and neodymium oxides the purity refers only to the rare earth oxide assay, however. Thus, care must be exercised to insure that contaminants do not affect the crystal growth or laser performance of fabricated rods.

Careful Procedures Required

The growth furnace is constructed by carefully aligning ceramic elements and the crucible for cylindrical symmetry. The oxides are blended to a homogeneous mixture and are then added to the crucible. In order to initiate growth, the melt temperature is adjusted to maintain the seed diameter when contact is made with the melt surface. If a diameter increase or decrease occurs, the temperature is adjusted upward or downward as required to maintain seed diameter. When pulling commences, the automatic diameter and temperature control systems are initiated and growth continues until the desired crystal length is obtained. The growth is then terminated and the entire furnace is cooled to room temperature over a period of several days.

The initial portion of the growth process consists of cutting all ceramic elements to the proper size prior to arrangement of the growth furnace. These are then dried in an oven to eliminate moisture introduced during the sawing process. This having been done, the growth station is constructed.

All components are centered with respect to the centerline of the pulling mechanism. The zirconia cylinders are placed concentrically within the outer quartz sleeve. Zirconia grog is then packed within all open areas to the top of the zirconia cylinders. This having been accomplished the iridium crucible is wrapped with a layer of zirconia felt, which is secured to the cruicible with sewing

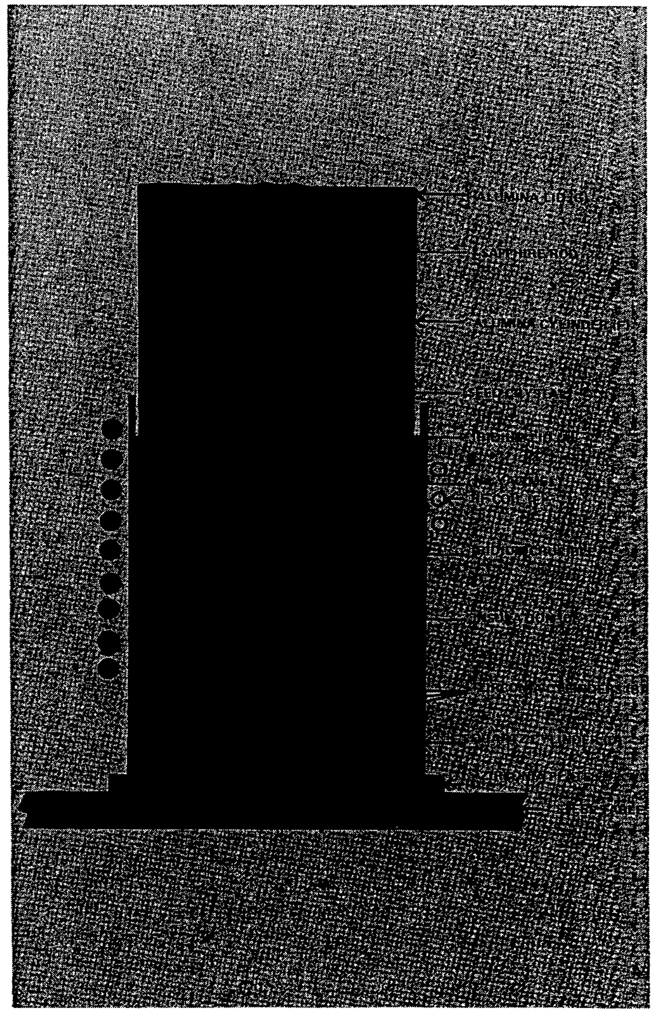


Figure 2

thread. The crucible is then centered atop the zirconia cylinders. The specially prepared insulation is added around the crucible to a position just below the top and the crucible lid is placed atop the crucible. Care should be exercised to insure that no contamination occurs on the crucible's internal surface. The growth station is completed with the addition of the alumina cylinder and lid, which act as an afterheater.

The growth furnace having been arranged, it is surrounded by a Pyrex bell jar, and the system is purged with a mixture of nitrogen with 0.05 percent oxygen. Power is also supplied at a low level to the crucible to eliminate residual moisture within the growth station. While this is being done, the crucible charge is prepared. The individual oxide components are weighed to 0.2 gm and blended for about one hour to insure thorough mixing. This mixture is then placed in clean beakers in preparation for loading of the crucible.

The crucible loading procedure should normally take several hours and is accomplished by gradually feeding the oxides into the crucible through a quartz tube while the power is increased slowly to melt the material. This operation is completed with a temperature at the melt center established below the crystal melting point. A seed holding mechanism is then fed into the growth station in preparation for initiating growth.

Prior to actual growth, a solid crystalline mass is generally present at the top center of the melt. This is dissipated by further adjustment of the power upward. A crystalline seed of the proper orientation is then dipped into the melt and the power is further adjusted to melt any solidified material back to the seed diameter. At that point the pulling operation is commenced.

In order to obtain the highest quality, an automatic diameter control system is utilized. The crystal is smoothly programmed from seed diameter out to its desired diameter and growth is allowed to proceed until a satisfactory length is obtained. At that point, the pull and rotation are stopped and the power is programmed down over several days.

Following extraction of the crystal, the crucible is removed from the growth station, the residual solidified melt is removed, and the crucible is cleaned. The growth station is then rearranged with a clean crucible and the growth process is repeated.

Early Run Examples

The first three growth attempts were designed to evaluate the performance of the control system with a new, larger power supply. A smaller 4-inch-diameter crucible was utilized with a standard growth station design (Figure 3) in order to make a comparison with results of growth runs made prior to initiation of the program. Some problems were experienced with melt contamination which originated from flaking of the quill used for holding the seed rod. This was caused by the higher temperature in the vicinity of the quill. Once the problem was identified, the diameter control system functioned normally, although poor control resulted from the effects of the contamination. For subsequent growth runs the larger 4.5-inch-diameter crucible was put into service.

A second series of growth runs were performed with a watercooled bell jar system. This approach was found to work very well since the excessive heat evolved from the growth furnace was effectively conducted away by the watercooled enclosure. Without this system it would have been impossible to work in the vicinity of the growth furnace; also, the heat would have had a deleterious effect on the electronic control system.

Growth at Seed Diameter

Experience in the production growth of Nd:YAG indicates that the best results are obtained if the crystal is

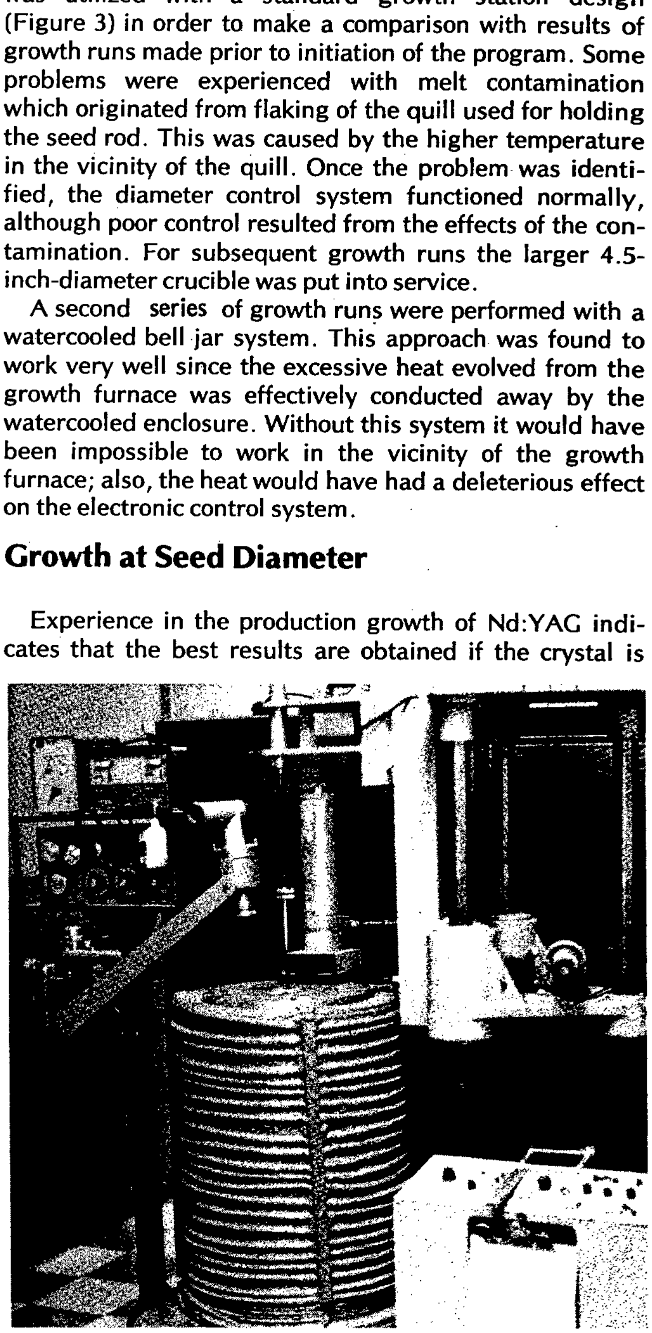


Figure 3

allowed to grow with a very steep solid/liquid interface projecting down into the melt. While this highly convex shape results in a core formation from facets developed at the tip of the growth interface, most of the strain is confined to a 3-4-mm-diameter core region. High quality laser rods can then be extracted from the outer portion of the crystal cross section and in between the radial strain lines.

An unfortunate consequence is that the disturbance of the crystal diameter normally results in a blossom (local high strain) fanning out from the central core. This situation also exists if the growth interface is not convex enough, since the faceted central region then has a tendency to trap liquid or secondary phases which result in defects.

Methods of insuring that the crystal maintains a highly convex profile are either to provide large temperature gradients or to utilize low rotation rates. The latter method alone is not very effective in the growth of Nd:YAG, since the rotation rate has little effect on interface shape except at high rotation rates (100 rpm). Thus, the former method is resorted to for production growth.

For the situation which exists during growth of the larger diameter crystals, care must be exercised because the crucible size and growth station design tend to increase the temperature gradients. Efforts to increase the existing gradients can lead to cracking when the yield strength of the crystal is exceeded.

Most of the initial work during this program favored crystals which contain blossoms arising from a shallow interface shape. In many cases the resulting strain was so gross that extensive cracking of the crystals resulted. Blossom formation occurred at diameters of 0.5-1.0 inch. An alternate method of lengthening the growth interface was attempted, and early results indicate that some improvement in growth occurred. In this instance, initial growth was conducted at somewhat larger than seed diameter for an extended length and the crystal diameter was then increased slowly to its final value (Figure 4). It was felt that the additional heat sink capacity of the extended length of small diameter crystals would provide a steeper growth interface and therefore overcome the blossom formation in the 0.5-1.0-inch-diameter range. Radiative losses could then maintain the steep interface as the crystal diameter was increased. Whether an improvement in growth results from this approach was not clear, since only two growth runs were completed with this technique.

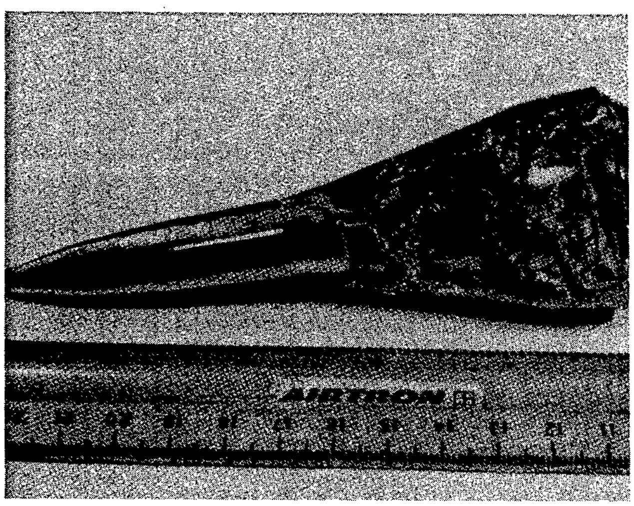


Figure 4

Melt Gradients Most Important Parameter

It is felt that the most important parameter requiring control during the growth of Nd:YAG is the radial melt temperature gradient. Because of the crystal's high melting point (1950 C), it is difficult to measure a gradient directly by accurate methods. One approach which has been utilized satisfactorily is to scan the melt surface with the optical pyrometer used for diameter control. This method has been found to be repeatable and has proved to be useful for qualifying the growth results of various growth station designs.

Figure 5 illustrates the results of two such scans for different growth station designs. Although similar in some respects, these charts have one characteristic which may be related to blossom formation at small crystal diameters. It can be seen that the radial melt temperature gradient is higher at smaller melt radii and then decreases as the distance from the melt center increases. This means that constitutional supercooling can occur at small crystal diameter if the rate of the diameter increase exceeds the ability of the diameter control system to maintain the crystal on its program. Ideally, the radial gradient should have a low slope more typical of that observed at the larger radii in Figure 5.

Problems Analyzed

The major difficulty which has prevented growth of larger diameter crystals of high quality has been the internal blossom generation at small crystal diameter. This has led to an inordinate amount of strain in most cases and

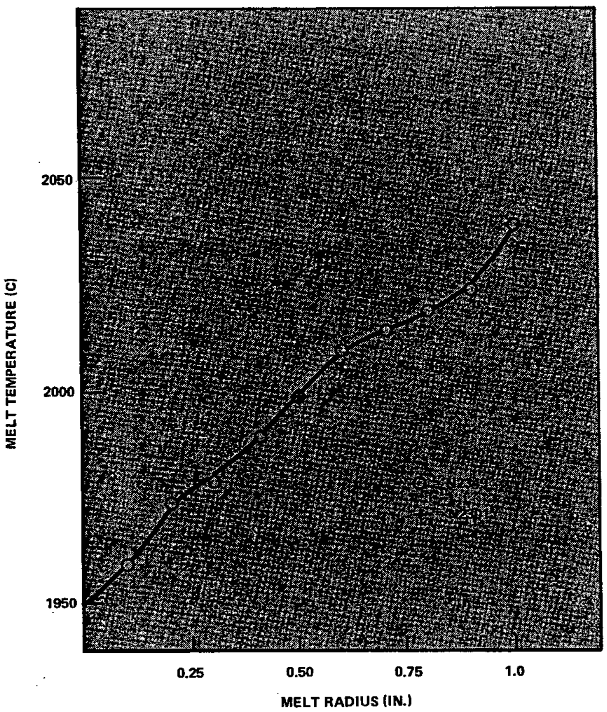


Figure 5

finally the crystal cracks. However, even in the cases where the strain from blossom generation is comparable to that encountered in production growth of smaller diameter crystals, cracking has occurred. It would appear, therefore, that the larger diameter crystals are unable to withstand the greater differential thermal stress between the cold surface and hot center of the crystal. A simple remedy for this appears to be a top heater.

The most recent growth results indicated that defect-free crystals of even larger diameter should be obtainable. While improving the growth station design, attention should be given to the area above the crucible into which the crystal is pulled during growth. Better insulation of this chamber should reduce the thermal loss and thus the differential thermal stress and tendency toward cracking. However, this is expected simultaneously to affect the radial and axial gradients so that blossom generation is prevented and thermal shock is alleviated.

The greatest difficulty in this program, however, has come from defect generation as the crystal approaches final diameter in its growth cycle. Although constitutional supercooling is inherent in the growth of Nd:YAG and slow growth rates must be utilized as a result, the aforementioned problem does not seem to be related mainly to growth rate.

Data on the typical radial melt temperature gradient were obtained with the growth station design. The most significant aspect of these data is that the gradient does not change much with small changes in the growth station design. While it would be desirable to obtain a gradient as near as possible to that existing in production, this leads to some serious problems with the growth stations involved.

One important feature is that a gradient of the required magnitude would push the crucible wall temperature close to the iridium melting point. This would make operation at growth temperature marginal and associated growth operations procedurally difficult. Another feature is that the additional heat loss from the growth station due to a higher radial gradient puts some constraints on the power supply in that the higher power output required raises the output voltage to a point where high voltage discharges tax the power supply's reliability. In spite of these difficulties a unique solution was found to modifying the radial melt temperature gradient. There appears to be a direct association between the institution of this change and the better growth results toward the end of the above experimental work.

Novel Approach

It should be noted that most of the insulating ceramics utilized for crystal growth are composed of zirconia. While this material possesses good thermal insulating properties by virtue of its relatively low thermal conductivity, it is also quite transparent to blackbody radiation at the crystal growth temperature.

Figure 6 represents a curve of the blackbody radiation from an emitter radiating at 2300 K, the approximate melting temperature of Nd:YAG. The peak of this curve lies at about 0.7 millimicrons where zirconia is transparent. Thus much of the infrared energy passes through the normal insulation used in the growth station. A material doped with dysprosium has very strong absorption at this same wavelength. A novel approach was utilized to effectively limit the amount of radiation escaping from the growth station and thus improve the insulating properties.

An alternate type of zirconia insulation was prepared by crystallizing the cubic form of zirconium oxide stabilized with dysprosium oxide rather than yttrium oxide or calcium oxide which are normally used. This material was prepared by growing dysprosium oxide (40 mole percent) stabilized cubic zirconia crystals with a patented growth process and then reducing these crystals to a granular

form compatible with the growth station design. This procedure was initiated with a growth run where the top two inches of insulation surrounding the crucible were replaced with the alternate insulation. A pyrometric probe of the radial melt temperature gradient for this run showed what appeared to be a refinement of the gradient near the center of the melt. While this was a gross measurement the true effect was realized when this crystal growth cycle was brought to completion without the crystal cracking. This was the first time a growth run at the large diameter was brought to completion in such a manner. The three subsequent runs also were completed by replacing all of the insulation surrounding the crucible with this alternate material. The absence of cracking in spite of extensive flaws indicated lower bulk crystal strain using this approach.

The real effect of this design change is not completely understood at this point but it is theorized that instability in the melt convection has been eliminated near the melt top center. Thus the tendency for generation of defects at the crystal core has been reduced. The next problem which has to be dealt with is some further modification of the growth interface to offset the tendency for defect generation due to constitutional supercooling. This has been approached initially by reducing the growth rate. However, this is an undesirable situation for improving the growth efficiency. It is believed at this time that the thermal convection in the absence of crystal growth is quite similar to standard production crystal growth. Further

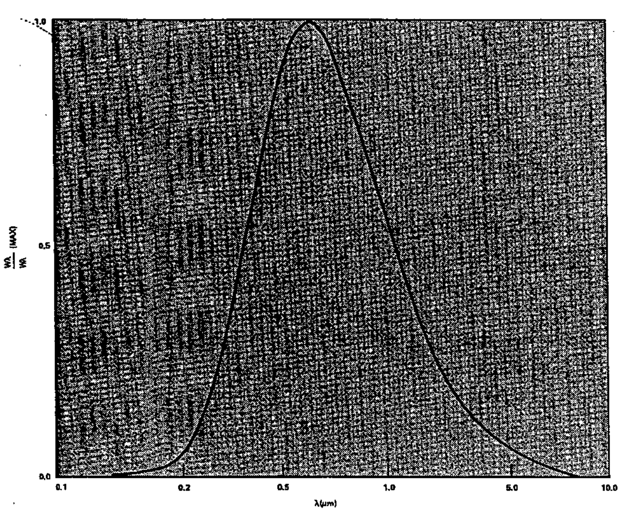


Figure 6

refinement in the growth can be expected, therefore, by evaluating the effects of crystal rotation rates on the growth quality.

Further Size Increase Possible

It was demonstrated early in this program that large Nd:YAG melts can be handled successfully for growth of 2.0 inch diameter boules by means of the Czochralski method. Ideally the crucible diameter should be about twice the boule diameter. The 50 kW and 450 kHz production radio frequency growth stations can melt easily the charges of 4.3 kg needed for large boules.

To grow good quality crystals, careful control of both longitudinal and radial melt gradients is necessary when a steep interface is present and faceting occurs. The most important of these is the radial gradient and for a large system it can be reduced by a judicious choice of insulation. Zirconia with a stabilizing additive of dysprosium oxide was found to give good results.

With an optimized growth station geometry and a given growth rate of 0.5 mm/hr, the remaining variable is rotation rate. In order to match the melt isotherms closely to the growth interface, values of around 15 rpm or less gave a high quality boule free of precipitates or strain.

A growth process was developed which gave finished boules meeting the suggested goals of 50 mm diameter and 75-100 mm long. Late in the contract, boules were obtained which yielded 40-60 laser rods of a (4.3 x 43) mm size. This was well above the goal of at least 30 rods which completely meet a current AN/GVS-5 specification.

All laser rods were fabricated by a batch process developed for polishing 15 rods in a single fixture. The engineering, confirmatory, and pilot production samples were extracted from production boules and fabricated under an existing rod process. Quality control passive tests of the rods showed that specifications were retained by more than 90 percent of the extracted rods.

It appears that the boule growth results obtained under this program are transferable to current production stations. Since only one station was in operation the entire length of the effort, insufficient growth statistics were generated to forecast high boule yields. Thus some problems of cracking, blossoms, poor starts, equipment failures, and materials choice are still apparent. On the average these are no worse than results obtained with smaller diameter boules.

Results obtained indicate that further increases in boule size are possible. However, the proper RF unit, diameter control, and furnace geometry need to be combined for growth near 3.0 inches.

Manufacturing Capability Established

Epitaxial Growth of GaAsP Material

by

Mrs. Marilyn Jasper
U. S. Army Night Vision & Electro-Optics Laboratory

Continued production of common module arrays for FLIR systems now is assured, following the successful completion of a U.S. Army Electronics R&D Command manufacturing technology project. Conducted by Honeywell Optoelectronics for the Army Night Vision & Electro-Optics Laboratory, the program was initiated in 1977 to provide a government manufacturing capability for arrays. At that time, the major supplier of GaAsP material was preparing to discontinue operation, potentially leaving no viable source. The uncertainty of a continuing supply of suitable high brightness material presented a threat to array production for the government.

The critical component of FLIR modules is the GaAsP light emitting diode (LED) array. A program to develop array technology had been initiated in 1975. Another program begun in 1977 established a dedicated facility for processing GaAsP material and assembling common module arrays. However, the program was dependent upon commercial sources for epitaxial GaAsP material.

Program Goals Set

Honeywell Optoelectronics had produced GaAsP material in the past. During 1975 and 1976, four vapor phase reactors were operated to supply GaAsP materials for digital LED watch displays. These reactors were the same type of reactor as was then commonly used to grow these epitaxial materials.

The approach for this program was to reactivate and modify one of the Honeywell vapor phase epitaxial reactors. Growth techniques were to be optimized and sufficient material was to be grown to process arrays. Assembly of arrays in the in-house facility would be used to demonstrate the quality of the materials grown. Finally, the program was used as a vehicle to develop and implement needed improvements in array production techniques.

Specific goals of the program were as follows:

(1) Modify one or more of the VPE reactors to produce epitaxial GaAsP material.

(2) Optimize material growth processes to produce material comparable to available sources.

(3) Implement standard inspection and test procedures to ensure conformation of epitaxial material to specifications developed jointly by Honeywell and NVL.

(4) Fabricate common module arrays from material grown on this program.

(5) Develop and implement improved assembly and testing procedures for array production.

NOTE: This manufacturing technology project that was conducted by Honeywell Optoelectronics for the U.S. Army Night Vision and Electro-Optics Laboratories was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The ERADCOM Point of Contact for more information is Bob Moore, (202) 394-3812.

Description of Reactor

The basic structure of the reactor used for the growth of gallium arsenide phosphide materials is shown in Figure 1. The reactor tube (chamber) proper is a quartz tube with provisions for a gallium reservoir, substrate pedestal, reactant gas entry, spent gas exhaust, and gas mixing. The chamber is heated by a multitemperature zone furnace to achieve the desired temperature profiles within the reactor. The temperature at each zone is regulated by an individual controller.

Reactant gases are supplied through a gas flow control system. The methods commonly used to control the amount of gas flowing into the reactor are (1) by restricting the flow through a capillary, or small diameter tube, or (2) by employing a mass flow controller.

The capillary tube method offers repeatable flow from one run to the next and provides a reasonably trouble-free and leak-free system. A drawback of this system is the method required to achieve graded composition. This method does not have the necessary versatility to produce either stepless grading or various composition profile grading.

In the second method a mass flow controller in conjunction with an analog programmer provides precise linear control of gas flow while ramping up or down at various rates. This allows grading to be performed in a stepless mode and allows rapid changes in grading programs.

Reactor Design and Modification

Both reactors used on this program were initially designed to operate using the capillary method of gas flow control. Early in the program, to Reactor #1 was operated unmodified. Epitaxial material was grown in this reactor. Material grown in this reactor initially had reasonable crystal morphology, but its operation was not reproducible. These results were attributed to leaks in the system and limitations of the gas control system.

Reactor #2 was modified to overcome these problems. It was redesigned to operate with mass flow controllers and automated sequencing. Additionally, improved plumbing connectors were used to eliminate leaks in the gas flow system.

Controls and interconnects for the reactor are housed in a cabinet adjacent to the reactor furnace as shown in Figure 2. Plumbing and wiring interconnects are within the cabinet; electrical and gas controls are located on the front panel.

A schematic diagram of the gas flow and control system used in the modified reactor is shown in Figure 3. All flow paths for the system are 1/4 inch stainless steel tubing. All hydrogen sources are controlled by micrometer needle valves. Pressure regulators are included in all of the supply lines to give consistent flow control. Air operated bellows valves in each line provide a fail-safe feature. In the event of loss of electrical power, all of the hazardous gases are cut off and nitrogen is fed to the reactor. Or if nitrogen is lost, all other gases are cut off.

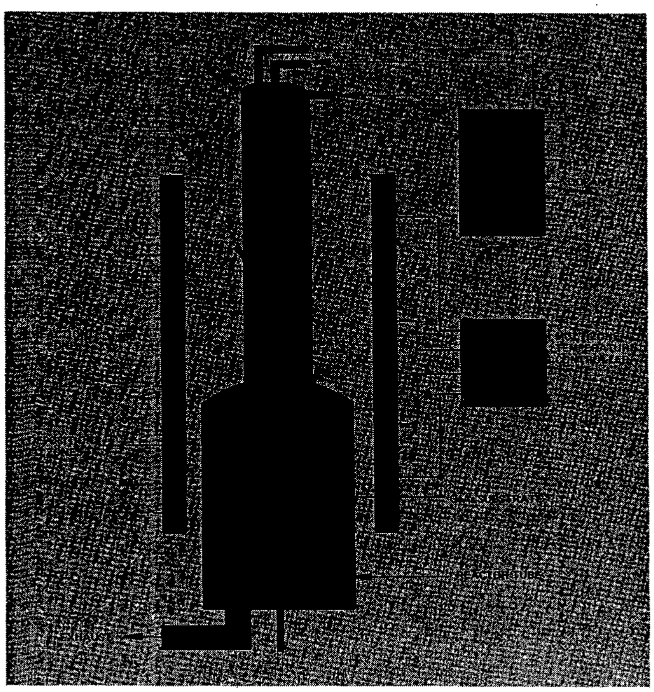


Figure 1

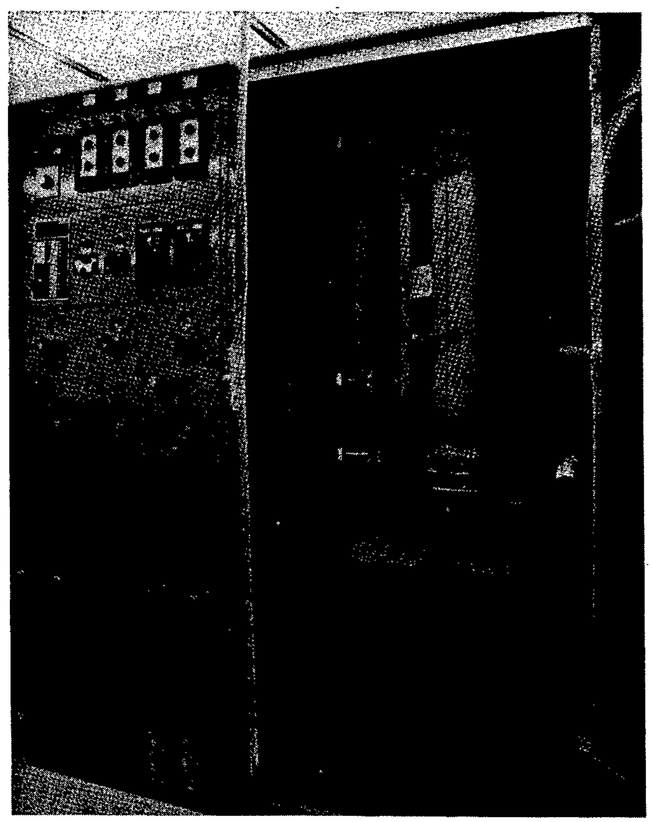


Figure 2

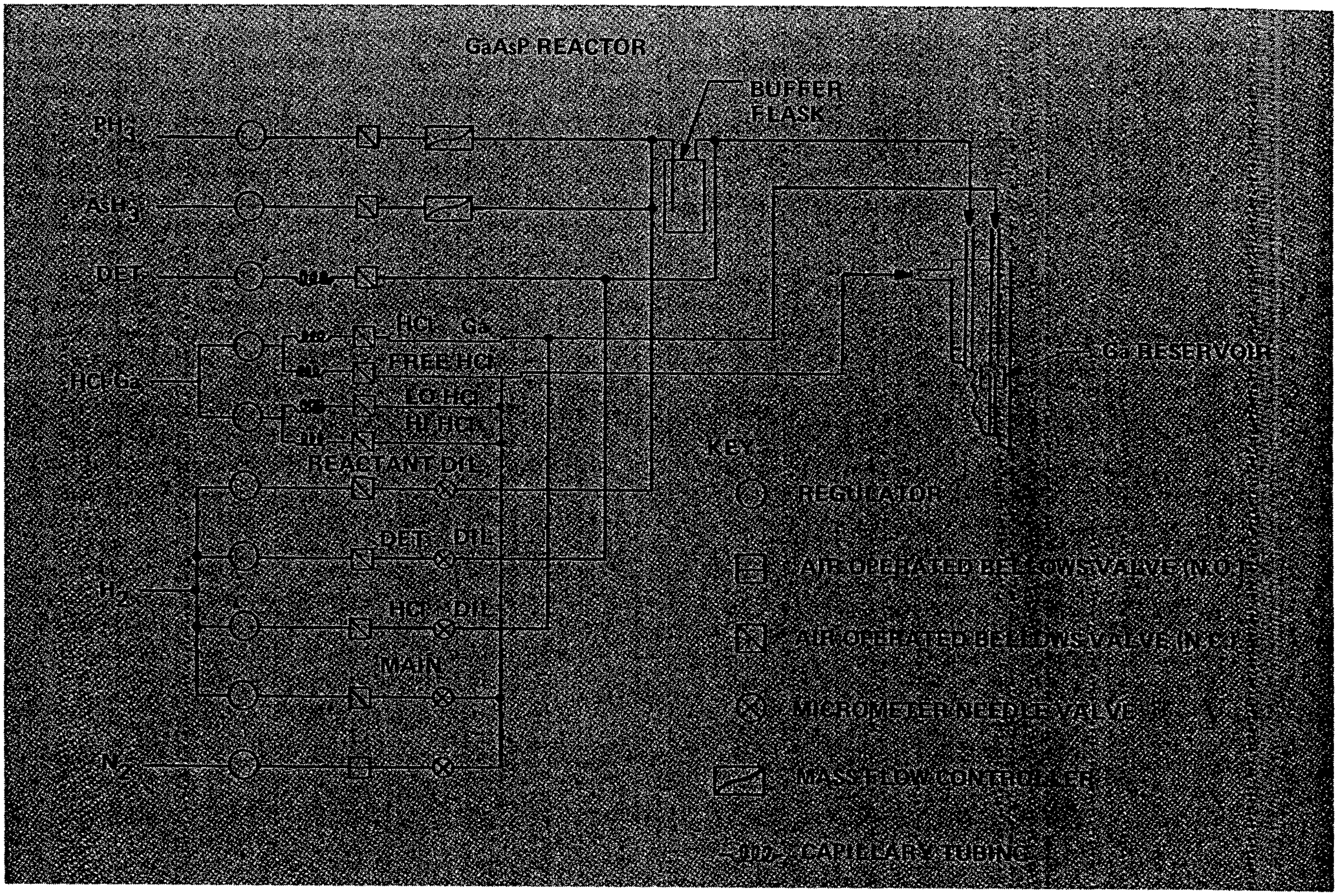


Figure 3

Reactor Facility Set Up

The complete reactor facility used for this program contains equipment required for material preparation, epitaxial growth, and characterization. A layout of the three rooms which comprise this dedicated facility is shown in Figure 4.

Up to 10 different locations can be sampled in a programmed sequence in a period of 25 minutes. Samples are fed to the monitor from each of the reactors, from the cabinets containing the arsine and phosphine cylinders, and from two points directly behind the reactor. They are analyzed by means of a gas chromatograph column. The monitor is calibrated automatically to a standard source after each eight-hour shift. Contacts on the monitor activate an alarm when the threshold limit value of arsenic (0.05 ppm) or phosphine (0.03 ppm) is exceeded.

A hydrogen detector is located next to the arsine/phosphine monitor. Two separate sampling channels are connected to the hydrogen detector. One is located in the reactor room directly behind Reactor (No. 2); another is located in the gas storage room.

Material for characterization of the GaAsP epitaxial layers is also located within the reactor facility.

Material Growth

Following epitaxial growth, slices are characterized to determine quality, composition, and doping of the epitaxial layers. Material specifications were developed for this program to provide a quantitative evaluation criteria. Tests were devised to determine conformance to these specifications.

The epitaxial structure used on this program consists of a $GaAs_{(1-x)}P_x$ layer grown on a GaAs substrate, as shown in Figure 5.Visible LED's are formed in the surface layer, which is of constant composition. For this region, x is adjusted to give the desired wavelength.

Visual Inspection

After prescreening to assure reasonably good material, slices are inspected with a low power microscope under illumination to obtain a surface reflection. A shiny reflec-

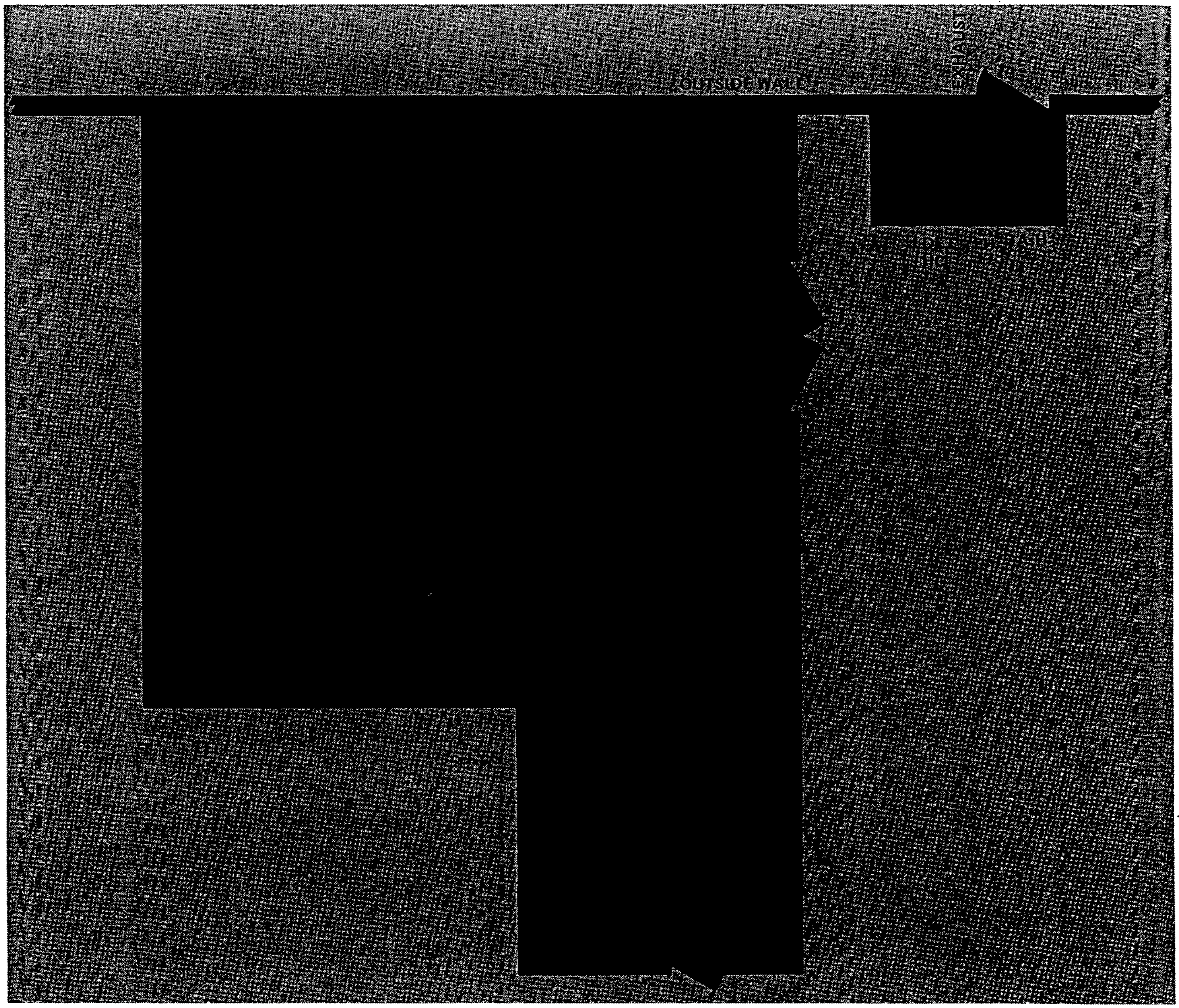


Figure 4

tion indicates good surface morphology. If dark spots or lines appear, the wafer is examined more closely under a powerful metallurgical microscope. Projections, voids, and scratches are evaluated quantitatively to determine conformance to the specifications.

Composition of the GaAsP epitaxial layer is evaluated with a photoluminescence test system. This apparatus, schematically shown in Figure 6, includes a He-Ne laser, lock-in amplifier, monochromator, and preamplifier. Correct composition is indicated when the peak photoluminescence wavelength is in the specified range.

Rough Surfaces A Problem

Material from early runs with Reactor No. 2 was not acceptable because of very rough surfaces. This was attributed in part to surges of phosphine which occurred when the mass flow controller was activated. A grading flask was added to the source line to moderate these surges. Surface and linearity of grading were substantially improved; however, there were still excessive surface irregularities. This problem was eventually solved when a defective SCR and an intermittent solenoid were identified and corrected. When good surfaces were consistently attained, the composition and doping were adjusted to meet the material specifications. Correlation between growth parameters and characterization parameters provided the basis for systematically adjusting the growth process.

Figure 7 shows photographs of cross sections for GaAsP epitaxial slices. The slice of Figure 7(a) is from an early run grown in Reactor No. 1. Discrete steps which result from switching the capillary tube are evident as distinct bands in the graded layer. The slice of Figure 7(b)

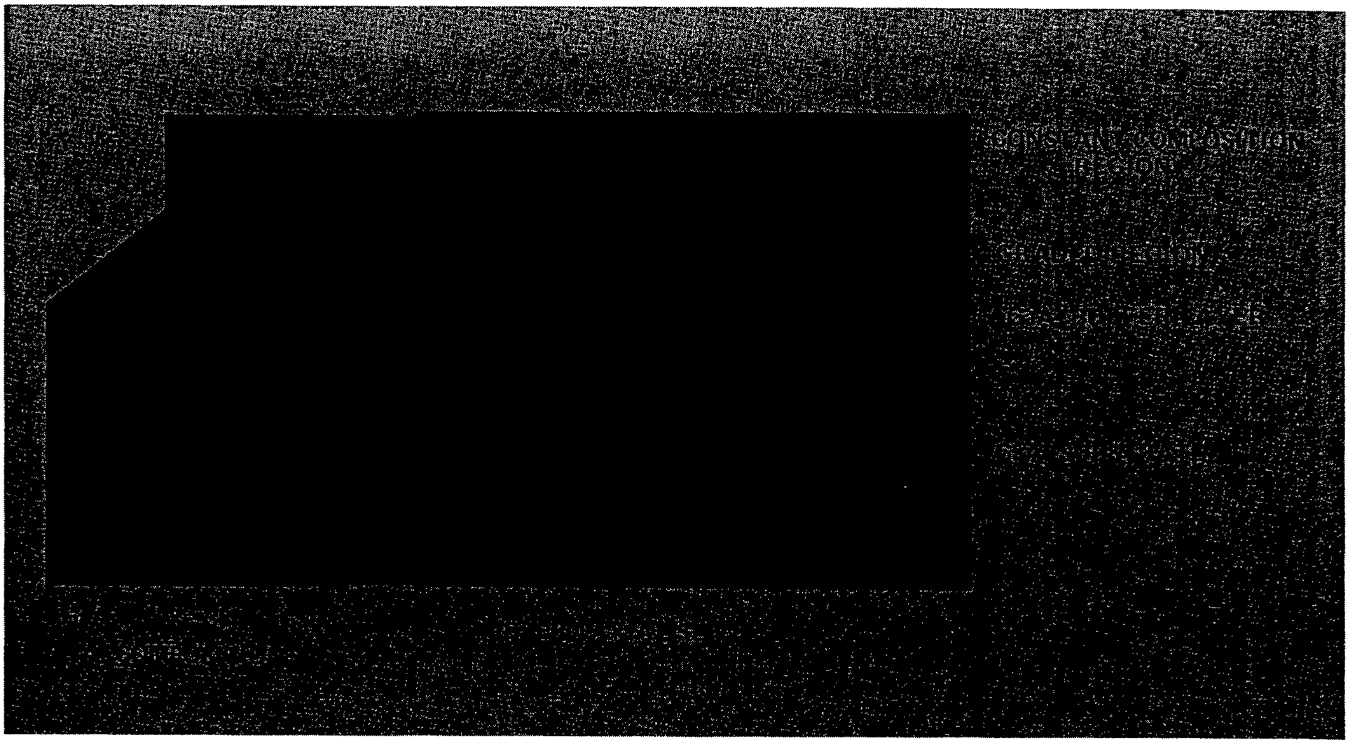


Figure 5

was grown in Reactor No. 2, modified with the mass flow controller. The smooth transition of the graded layer exhibited in this slice is desired for low dislocations and defect density.

Slice lots were processed as needed to adjust material growth parameters and demonstrate reproducible runs. When the capability to produce array quality material was achieved, sufficient epitaxial slices were grown for evaluation samples and to supply material for processing of arrays.

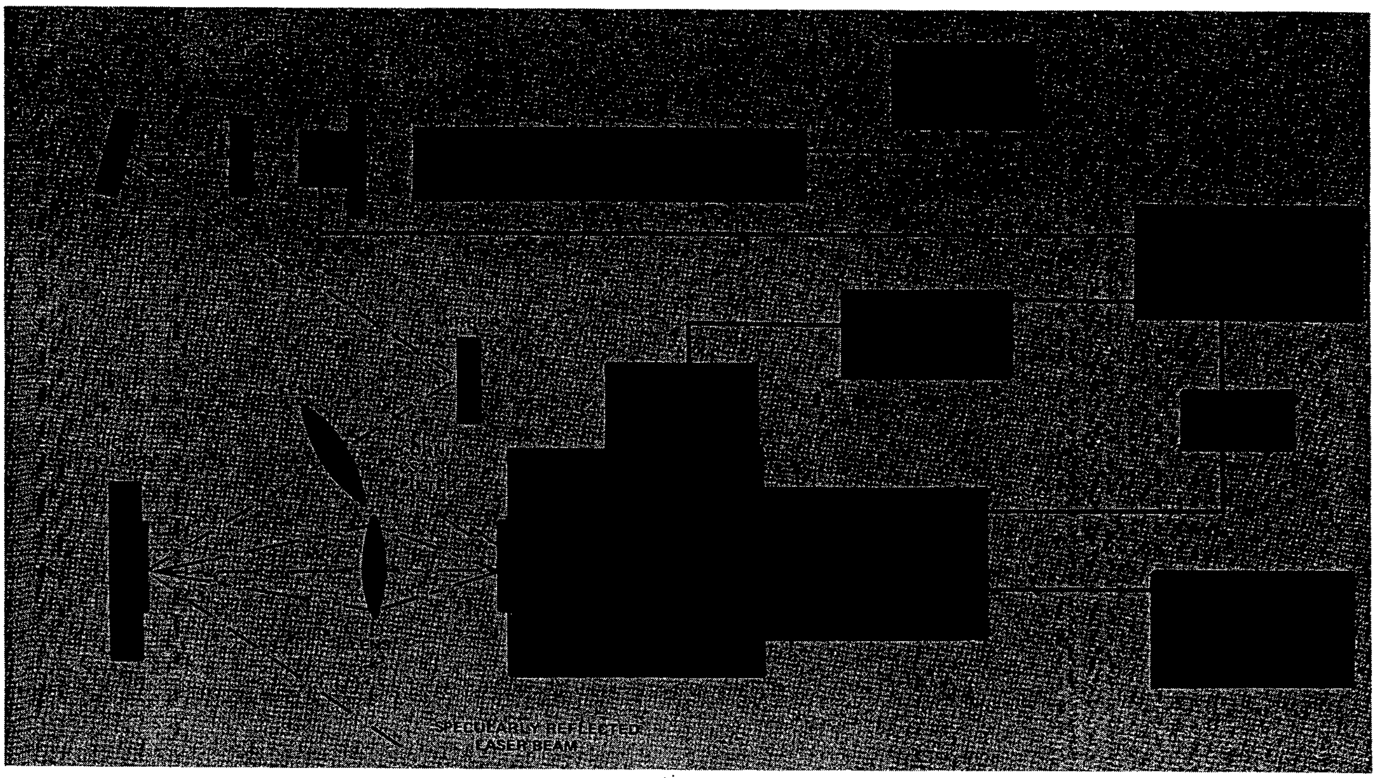
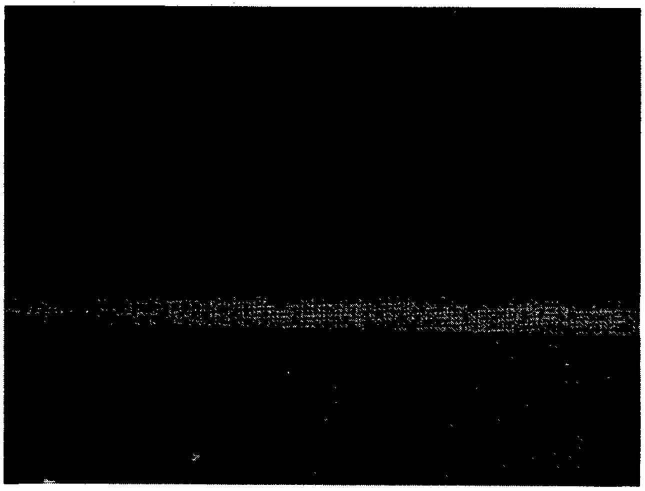
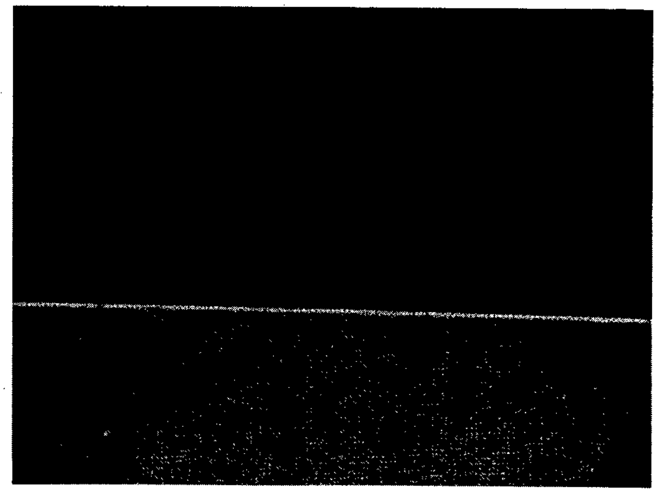


Figure 6



(a) **EPITAXIAL LAYER GROWN WITH CAPILLARY TUBE CONTROL**



(b) **EPITAXIAL LAYER GROWN WITH MASS FLOW CONTROLLERS**

Figure 7

Assembly and Test

Honeywell has a dedicated in-house facility for assembly and test of common module arrays. Following front end processing, slices are probed to test and identify good arrays. Software is available for probing both 90 and 180 element types.

When good arrays are identified at wafer probe, they are sawed out and visually inspected. The arrays are then eutectic solder die attached to a metallized ceramic header.

Common module arrays using material grown on this program were fabricated in the in-house assembly area. One each 90 element array and 180 element array which met all specifications were delivered.

Tasks Studied

This contract studied four areas of manufacturing improvement. The tasks were defined as follows: automatic resistor placement, flange focal length measurement, identification of arrays on wafer, and improved array lead geometry.

- Automatic resistor placement—an LED module with laser trimmed resistors integral to the substrate was delivered.
- Flange focal length measurement—this task was terminated when existing measurement capabilities were shown to be adequate.
- Identification of arrays on wafers—performance of automated inkers was shown to be acceptable.
- Improved array lead geometry—three LED modules of the "single sided" geometry were delivered. Implementation of this approach is optional to user activities if this version is deemed necessary.

Decontamination Unnecessary

Resistant Paint to Protect Vehicle Crews

By George Taylor
U.S. Army Tank—Automotive Command

TACOM is playing a key role in a program to convert Army vehicles from the current alkyd paint to chemical-resistant paints that will improve nuclear, biological and chemical (NBC) crew protection.

The paint conversion program begain in 1982, following an Army decision to convert its entire fleet of some 400,000 combat and tactical vehicles.

The initial goal is to start painting all new vehicles in October 1985. Then, if all goes well, the Army expects to begin painting existing vehicles during routine depot maintenance.

The TACOM effort falls under the Department of Defense's Manufacturing Methods and Technology (MM&T) program. The aim of this program is to improve military equipment and reduce its production costs by applying advanced technology to establish better manufacturing methods.

The ultimate goal of the TACOM MM&T paint project is to demonstrate the validity of using robots to paint M2/M3 Bradley fighting vehicles on the assembly line with chemical resistant paints.

According to Michael King, MM&T paint project engineer in TACOM's R&D Center, general-purpose robots are now available that can paint vehicles. King said the purpose of the Bradley vehicle demonstration is to establish a procedure that could be used to paint other Army vehicles with robots.

Camouflage Patterns Sophisticated

"One reason we are looking at robots," said King, "is that the camouflage patterns used on our vehicles are becoming more sophisticated. As a result, painting these patterns manually is now very labor-intensive. But if we can program a robot to do it, the robot can paint the pattern over and over with remarkable repeatability.

"Another advantage to a robot," he added, "is that it uses less paint to cover a surface than a manually operated spray gun does."

The new paints, called chemical agent resistant coatings (CARC), are made either from polyurethane or epoxy. They provide a barrier of protection agains toxic chemical agents that may be present in a battlefield environment.

When alkyd paint is exposed to such chemical agents, it allows them to penetrate the paint surface. So once a vehicle has been exposed, the only way to remove all the contaminant is to strip the paint by using corrosive decontaminants.

CARC Paint Nonabsorbant

But, according to King, this is not necessary with CARC paints, because the are nonabsorbant.

"The chemical agents remain on the surface," he explained. "So they can be removed with decontaminants without destroying the paint."

Following the Army's decision to make the changeover, TACOM funded two projects aimed at reviewing available CARC primers and topcoats, painting equipment, health safeguards, monitoring equipment and quality control requirements.

One of these involves the Belvoir Research and Development Center (BRADC), Ft. Belvoir, Va., which is responsible for preparing Army vehicle paint specifications.

The other project is a contractual effort with the California-based FMC Corp., the firm which produces the Bradley vehicles.

NOTE: This manufacturing technology project was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The TACOM Point of Contact for more information is Don Cargo, (313) 574-8709.

EPA, OSHA Standards Met

At BRADC, engineers are testing various epoxy- and polyurethane-based paints and primers to find those that would meet Army, Environmental Protection Agency, and Occupational Safety and Health Administration requirements. This effort is not yet completed but has so far resulted in the approval of four epoxy primers, three epoxy topcoats and five polyurethane topcoats.

Meanwhile, FMC has been testing the BRADC-approved coatings under simulated production conditions. To date, the firm has chosen a CARC primer for the Bradley vehicles, but has yet to select a topcoat.

King said that once all test results are in and FMC selects a topcoat, the final step will be for FMC to install the robot system and program it for camouflage painting. He said the feasibility demonstration is expected to take place next October—one year ahead of the Army's target conversion date.

CAMOUFLAGED BRADLEY AIRBORNE DURING TESTING

Non-Planar PC Program Results

Semi-Additive Printed Wiring

ROBERT L. BROWN is a General Enginner at the U.S. Army Missile Command at Huntsville, Alabama. He is responsible for the creative direction of contractor engineers on projects such as the Non-Planar Printed Circuit Board development. He holds a B.S. in Metallurgy from Alabama University and is a Registered Professional Engineer in the State of Alabama and is credited with 8 patents. Among his many achievements are: a television X-ray imaging system and a patented method for brazing dissimilar metals.

Photograph Unavailable

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Successful production of extremely accurate fine line (to 5 microns) patterns over very large areas has led to a surge of activity in microwave passive circuitry; an application in the giagahertz range is the double-spiral wound antenna developed by General Dynamics' Pomona Division for the U.S. Army Missile Command. This particular achievement was the direct result of an MM&T project and a carefully formulated development contract initiated by the Command which accurately defined the guidelines for the work.

The Non-Planar Printed Circuit Program made use of both additive and semi-additive techniques to fabricate millimeter wave antenna components, broad band spiral antennas, and an innovative cylindrical circuit board assembly.

Significant recent work in fully additive and semi-additive manufacture established the importance of distinguishing between these two methods of manufacture and the need to formulate development contracts accurately to achieve the desired results.

The Institute for Printed Circuits additive round robin did not prove that military specification test levels could be met by additive printed wiring, but it did furnish convincing proof that the military should investigate the additive potential.

In the development phase of what became two contracted projects, a gradual division of additive processes into two groups was made and were defined as "fully additive", in which circuits were pattern plated from "bareboards" with electroless copper. This group was not successful in meeting specification requirements and

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NOTE: This manufacturing technology project that was conducted by General Dynamics' Pomona was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The MICOM Point of Contact for more information is Robert L. Brown, (205) 876-2147.

until added major improvements are made in materials and methods will not be acceptable for critical military use.

The second group was defined as "semi-additive", and it readily meets military requirements as well as having specific advantages in cost and quality—leading to its increasing acceptance and use in commercial products.

Definition Clarifies Objectives

A major factor in development of an acceptable process was in the care taken in preparing the contract, mainly in establishing and defining the term "semi-additive" in such a way as to confine the term to variants of the subtractive process. All variations include the necessary steps of producing "cladding"—a uniform metal coat of minimum thickness to allow electrolytic pattern plating of the circuit lines in the developed pattern of photoresist covering the clad surface. The correct line thickness is electroformed in the photoresist pattern, the photoresist being somewhat thicker than the metal deposited. The remaining photoresist is removed, and the cladding is removed by etching. Since this cladding is only microns thick, there are only miniscule dimensional changes in dimension of the pattern—too small in many cases to be measured.

These key steps establish the process as semi-additive. Results of the contracted investigation, carried out by Hughes Aircraft Company under a MICOM contract, were fully successful in that a high resolution process evolved that met all physical tests required by military specifications, with side benefits of lower cost than subtractive and the ability to produce much finer lines and closer spacing than any other high production process. Even before the contract ended, Hughes was producing boards and hybrid base-metal substrates by the process. Independent investigations carried out at Dynamics Research Corporation have shown success in routine production of five micron lines and spaces, with no apparent barrier to higher densities; this accomplishment lends confidence to the thrust for higher densities in printed wiring.

The double-spiral wound antennas developed at General Dynamics consist of two spirals three mils wide and one mil thick, with three mil spacing between lines and nearly an inch in diameter. As such, they provide very nearly a "worst case" demonstration of the semi-additive process capability in manufacture of high-density circuits. A less extreme, but equally interesting, development out of the General Dynamics effort was a non-planar (cylindrical) printed wiring board (Figure 1). While this was not an extreme example of forming, the demonstration of potential worth of formed components, even to folded boards, is particularly impressive in terms of increased reliability and lower costs.

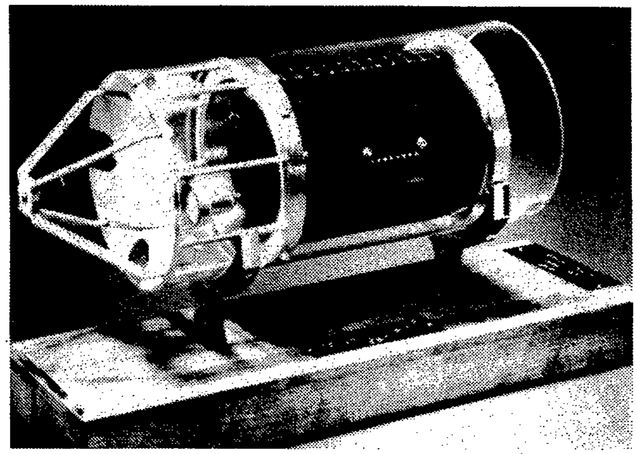


FIGURE 1. NON-PLANAR ANTENNA AND CYLINDRICAL CIRCUIT BOARD

Spiral Antenna Design

The design of the spiral antennas required for this effort was undertaken initially using an equiangular logarithmic spiral approach. Using the one-inch diameter specified and establishing that a two-arm spiral would be used in the application, the feed point dimensions were set at $\pm .050$ inch.

With these features defined, the equation of the equiangular spiral was written. This equation was used in the computer program to generate the coordinates of the spiral geometry. The coordinates thus obtained were then used to enable the generation of a glass negative via computer-aided design using a photo plotter.

The negative was applied to a teflon/copperclad laminate, and the spiral pattern was etched in the metallization to produce a functional circuit board.

Measurement Data

The goal for the broad band spiral operation was to operate from 2.75 GHz at the low end to 18 GHz at the high end of the frequency band.

The 8-wrap equiangular log spiral functioned better above 4 GHz than below that frequency. Therefore, an

attempt was made to increase the number of wraps of the spiral while keeping the same antenna diameter. In order to do so, criteria were established that the spiral should have a conductor line width of 0.005 inch and maintain a 0.005 inch space between the adjacent wrapped elements of the spiral. A computer program was written to accomplish this, which resulted in the ability to produce a 21-wrap, two-arm spiral on the required one-inch diameter. A test assembly for this version was put together and evaluated. This antenna version operated moderately well at 3GHz.

An effort was made to evaluate a slightly larger diameter spiral.

Using the same techniques as previously described, a spiral was fabricated and assembled to permit evaluation of a 1.1-inch-diameter spiral that embodied 23 wraps. The final spiral antenna utilized 3-mil lines and 3-mil spaces.

Spiral Antenna and Balun Fabrication Sequence

The material used to make spiral antennas and baluns was a double sided copper clad teflon laminate manufactured by Rogers Corporation. The laminates were drilled with registering holes, scrubbed, rinsed thoroughly, forced air dried, and placed in an over for 5 minutes. While warm, dry film photo resist was applied.

Precision glass negatives were generated by CAD/CAM techniques (Figure 2). The spiral antenna glass negative is shown in Figure 3. The protective mylar was discarded from one side of the resist-covered spiral laminate. A polyvinyl alcohol solution was prepared with PVA, deionized water, and triton wetting agent. After filtering, it was poured over the laminate and allowed to dry.

After properly registering the laminates in their glass negatives, they were individually placed in an exposure unit. The spiral antennas and baluns were exposed to ultra-violet light.

The laminates were placed in a spray developer solution which removed the resist where it had not been exposed, leaving resist-covered circuit patterns. They were rinsed thoroughly and forced air dried.

The laminates were examined under magnification (Figure 4). The spiral circuits were too small to be touched up. If they were not perfect, they were not processed further. The parts were spray etched by warm ferric chloride, which removed copper where it was not protected by resist. The parts were immediately rinsed sequentially with water, dilute hydrochloric acid, deionized water, and then forced air dried.

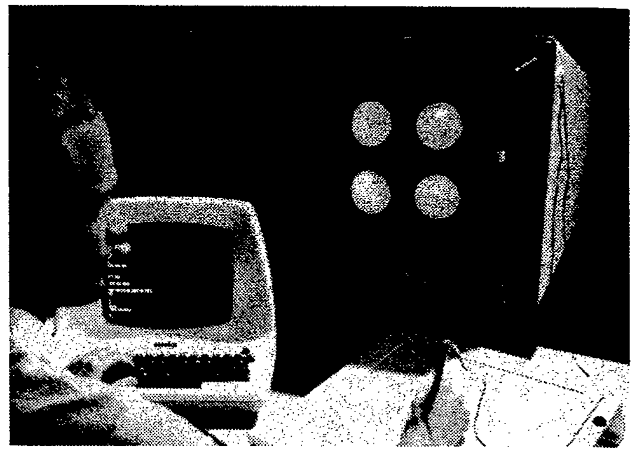


FIGURE 2. SPIRAL ANTENNA NEGATIVE GENERATION BY CAD/CAM TECHNIQUES

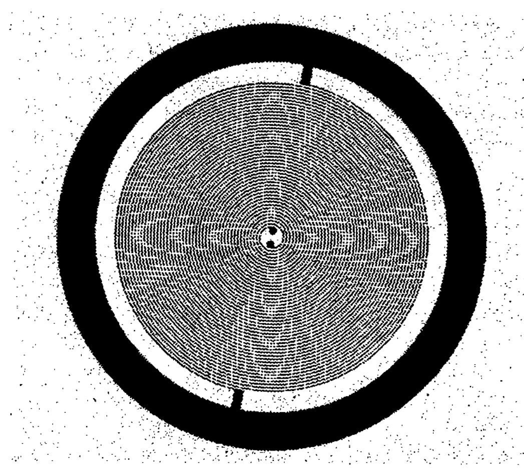


FIGURE 3. SPIRAL ANTENNA GLASS NEGATIVE

The spirals were examined to ensure sufficient etching. Small bridges were eliminated by careful use of a razor blade. The resist was stripped off and the parts were sequentially rinsed with water, dilute hydrochloric acid, water, and forced air dried. This concluded the balun processing.

In order to etch the copper off the back of the spiral laminate, resist was applied to the front only. It was etched, resist was stripped, the spirals sequentially rinsed with water, dilute hydrochloric acid, water, and forced air dried. The spirals were again examined for defects and the circuit widths were measured.

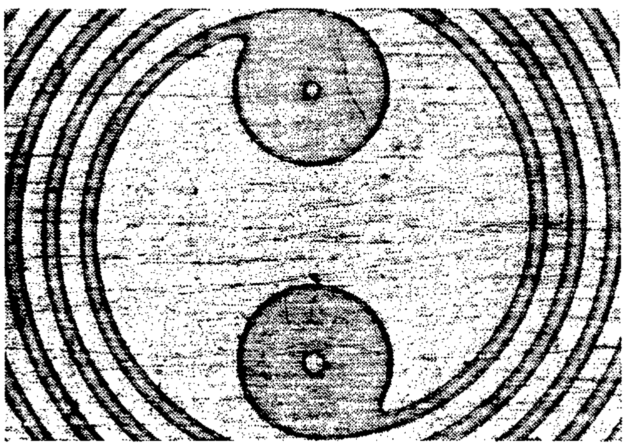


FIGURE 4. INSPECTION OF SPIRAL ANTENNAS BEFORE ETCH, MAGNIFICATION 85X

The spirals were drilled in the circuit pads and tooling, and then were gold plated and die-cut.

Electroless Copper Plating of Union Carbide Mindel A-650

After molding and machining was completed, a conductive nickel/copper/gold (or copper/gold) coating was applied onto the polysulfone parts. This plating proces was made up of several distinct subprocesses: preparation swelling, chromic acid etch, catalyzing, electroless plating, electrolytic plating, polishing, and gold plating.

The parts were annealed to remove molded-in stresses. The parts were hand washed in a mild soap solution, rinsed in a flow-through rinse, and placed onto a special rack which prevented contact between them and allowed full exposure to all chemical baths.

The polysulfone parts were immersed in a hot aqueous solution in order to remove any residual contaminates and were spray rinsed in deionized water. They were then immersed in a hot aqueous solution with work agitation and moderate stirring. This was immediately followed by immersion in an agitated flowthrough rinse.

Chromic acid etching of the swelled polysulfone could then proceed. Parts were immersed in a hot chromic acid solution which was both vigorously air agitated and ultrasonically agitated. The parts were removed from the chromic acid etchant and placed directly into an air-agitated reducer solution with immersion time depending upon part complexity. Parts were then spray rinsed and subsequently placed into an ultrasonically agitated heated reducer solution. Next, parts were immersed in a hot flowthrough rinse, then immersed in an agitated aqueous solution. The parts then were thoroughly flow through rinsed.

The catalyzing sequence began by immersing the polysulfone parts into a hot aqueous solution followed by a turbulent flowthrough rinse. Parts were then placed into a heated prep solution with part agitation.

Next, parts were directly transferred into a heated and stirred solution. Upon removal from this solution, the part surface would appear a uniformly muddy brown. Lighter areas indicated uneven catalyzing and were minimized by the following technique: The parts were immersed in a stirred accelerator solution and parts were removed and rinsed in deionized water. The parts surface appeared a light, uniformly grey color, which indicated that the parts were properly catalyzed and ready for electroless plating.

All parts, except the hyperbolic subreflector, were then placed into an electroless nickel solution. Following a brief rinse, all parts were placed into an electroless copper solution and parts were then rinsed and air-dryed prior to electrolytic plating. Electrolytic plating began by dipping the electroless copper plated part into a furic acid solution followed by a brief flowthrough rinse. This was followed by electrolytic acid copper plating with a ductile acid coper with good "throwing" characteristics (i.e., able to adequately plate through-holes). The parts were then "bright-dipped" in a chromic acid solution, rinsed, and oven-dried.

Polishing was necessary for both the hyperbolic subreflector and the parabolic main reflector. Both parts were simply buffed to a mirror finish. The waxy polishing compound was removed by immersion in a hot alkaline cleaner, followed by thorough rinsing. The main reflector was then ready for electrolytic gold plating (the fourport waveguide required no polishing).

Prior to gold plating, the main reflectors were dipped in an acid cleaner solution and rinsed in a deionized water flowthrough rinse, activated, and given a thin coat of electroless copper. The parts were then placed in an electrolytic cyanide gold plating solution and electrolytically plated. In this manner, a conductive, protective coating with adequate adhesion was applied.

Subreflector Grid Process

An acetate filmset with the necessary artwork photographed onto its surface was formed with a combination of heat and vacuum pressure to conform to the surface of the hyperbolic subreflector. This filmset was used as

the master negative for photosensitizing the photoresist.

To begin the process, a polished and cleaned subreflector was spun on a resist spinner while resist, was applied (Figure 5). It was baked to cure the resist and then placed in a special vacuum fixture. The non-planar artwork was placed onto its surface and a sheet of teflon release film applied with vacuum tape. Vacuum was then applied to the assembly, ensuring intimate contact between artwork and photoresist; the fixture was exposed on a printer at low power. The developing process consisted of two separate immersions into ortho resist developer. The developing step was followed immediately with an isopropyl alcohol dip and forced air drying. The developed image was then cured.

The subreflectors were spray etched with a ferric chloride solution and were cleaned and inspected for dimensional accuracy. The resist was removed from the subreflector by polishing with a cheesecloth and liquid polishing compound. The subreflector was cleaned, painted, and installed onto the main antenna assembly.

FIGURE 5. APPLICATION OF PHOTORESIST

Cylindrical Circuit Materials and Process Evaluation

The basic intent of this program was to find a material/process system to produce semi-additive military printed circuit boards having a cylindrical shape.

Five potential constructions were evaluated to manufacture cylindrical single-sided, double-sided, and multilayer printed circuit boards. Extensive work was done to evaluate each processing step in the various constructions for complexity, cost, ease of manufacture, and potential for having a 95 percent confidence level of successful performance.

(1) **Glass-Reinforced Polyimide Supported Copper-Clad Substrates** capable of being bonded with B-stage glass supported polyimide adhesive layers was the first construction to be evaluated. Here, the innermost pre-etched layer would be wrapped around a mandrel and bonded with a B-staged polyimide adhesive system. Subsequent pre-etched layers would be registered with the first layer by the use of tooling pins and then bonded with adhesive layers. A unique bonding method was developed by General Dynamics Pomona several years ago to laminate composite wings and fins. This methodology was called elastomeric pressure bonding. A silicone potting resin was cast to a cylindrical shape and placed against the layers to be bonded. The layers and silicone form were restrained by the inner mandrel and outer box. The assembly was then placed in an oven, causing the silicone rubber to expand and exert uniform pressure and thus allow the B-staged polyimide adhesive to cure. Using this method for bonding eliminated the need for elaborate tooling and expensive presses. The cylindrical laminate was then ready for drilling. A special four-axis, high-speed, NC-controlled drill head was needed to complete this task. Even with the holes drilled, the elaborate and expensive vacuum and exposure equipment required to image the inner and outer layers after plating through the holes made this process costly, complex, and unreliable.

(2) A similar approach was undertaken using **Unreinforced Polyimide Copper-Clad Substrate.** These flexible layers were bonded using B-staged glass supported polyimide adhesive layers. By effectively removing half of the glass reinforcement, it was felt that conventional processing steps could be utilized. After processing, the laminate was wrapped around the mandrel. During this process the board delaminated and cracked due to the stiffness of the glass reinforcement. This approach was abandoned.

(3) An evaluation was made of **Polysulfone Copper-Clad laminate Samples.** The samples were pre-etched and thermoformed using heat and pressure over a mandrel. This system looked promising until it was found that Norplex (sole source of polysulfone/Cu

clad laminates) had decided that the market could not support their product and a production facility was never built.

(4) A fourth construction evaluated was the use of **Injection Molded Polysulfone.** By utilizing injection molding techniques, it was possible to eliminate the costly drilling step. Pins could be built into the mold to allow for "molded in holes". Expensive tooling would be required to injection mold the four individual components. Each layer would have to be additively plated, imaged, and etched in a cylindrical configuration. This processing sequence, very similar to that previously described in (1), was very complex, and costly.

(5) The evaluation led to the use of **All Flexible Materials.** Flexible printed circuits for electrical interconnections have been an important production item for many years. They have replaced mazes of "hard wiring" for assembly simplification, neatness, maintainability, weight and space reduction, and reliability, all of which are crucial in military electronics.

A description of the production steps used to manufacture a multilayer cylindrical circuit board using all flexible materials follows.

Artwork Generation

Artwork for the eight-layer cylindrical circuit board was generated using a computer-aided design system. A single circuit path was generated to interconnect each layer to a connector pad.

Cylindrical Circuit Board Fabrication

There were two types of starting materials used in the fabrication of cylindrical circuit boards. The first was a double copperclad laminate which consisted of a polyimide "Kapton" center surrounded by acrylic adhesive and copper on either side. The polyimide and the acrylic adhesive were of similar thickness. The second starting material was also polyimide bordered by acrylic adhesive.

An eight-layer printed circuit board was made by photoengraving a circuit pattern into both layers of copper and then laminating four of these etched laminates together using one sheet of bond ply between each.

Negatives of the circuit patterns were prepared for each of the eight layers. They were drilled precisely with tooling holes for use in registering the inner-layer circuit patterns (layers two through seven only) onto the laminates.

To begin fabrication of a cylindrical printed circuit board, four Pyralux sheets were mounted onto the numerical control drill shown in Figure 6 and drilled with tooling holes for subsequent lamination and drilling alignment and for registering the negatives onto layers two through seven.

FIGURE 6. NUMERICAL CONTROL DRILL

The four laminates were next scrubbed with acid cleaner and scotchbrite pads to remove oxidation. They were rinsed thoroughly, dried well, and placed in an oven. While still warm, dry film photoresist was applied using a roll laminator. Air pressure in addition to the roll pressure was used for strong adhesion. The photoresist was a light, sensitive material which polymerized upon exposure to ultraviolet light, becoming hard and insoluble in the developing solution. Hence, from this stage until developed, the resist-covered laminates had to be protected from white light except when covered with a properly registered negative.

The resist covering the tooling holes was burned out using a solder iron and tooling pins were inserted. Negatives for layers two through seven were placed over the pins and taped into position. The pins were then removed. The negative-covered laminates were next individually exposed on a light exposure unit.

The negatives and the photoresist's protective mylar were removed from layers two through seven. A convey-

orized developer containing a solution removed the resist where it was not exposed, leaving resist circuit patterns on the inner layers.

Under magnification, the inner layers were examined. Any extra resist was removed with Q-tips and Xylene. Breaks in the pattern were painted over with acid resist. The tooling holes around the periphery were masked to protect them from stretching during lamination.

Warm ferric chloride pumped over the inner layers by the conveyorized etcher removed the copper where it was not protected by the photo resist. Hydrochloric acid automatically rinsed off the hydrochloric acid. The resist's mylar was discarded from layers one and eight. They were examined to ensure there were no broken circuits.

The photoresist was stripped off and the circuits were dipped in dilute hydrochloric acid and scrubbed again with acid cleaner and scotchbrite pads.

Using a straight edge and razor blade, the inner layers were trimmed according to preimaged guidelines, which had been placed so as to ensure proper fitting together of the ends when bonded into a cylindrical shape. The bond plies were trimmed at the same time, using the inner layers as templates. They were wiped clean using alcohol and a cloth.

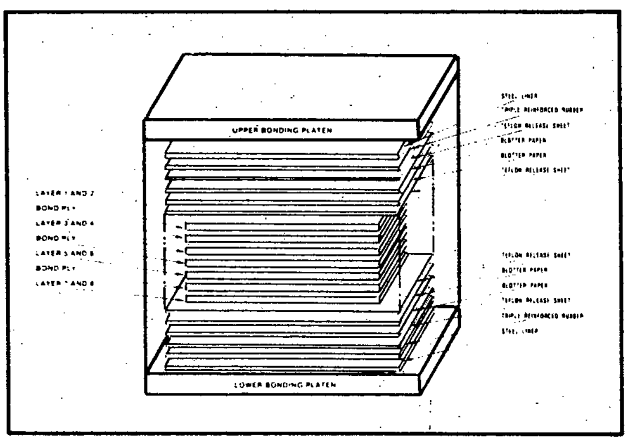


FIGURE 7. LAMINATION LAYUP

Teflon placed between the layers allowed air and moisture to escape while they and the bond plies were baked.

Immediately after removal from the oven, the lamination package was layed up as illustrated in Figure 7. It was registered together using the holes previously drilled. The mylars were removed from the bond plies.

It was found that the triple reinforced rubber/blotter paper combination provided excellent results. It was solf enough to provide adequate pressure on both the areas containing copper circuitry and the thinner areas where the copper had been etched off. The blotter paper provided excellent dimensional stability, preventing stretching. Also, smooth blotter paper gave rise to a smooth surface in the region used to bond the printed circuit board into its cylindrical shape.

The package entered the press cold so as to allow air to escape before bonding occurred. It was cooled under pressure to ensure good lamination. To prepare for drilling, the laminated board was registered onto the numerical control drill using the tooling holes used during the lamination layup. A coupon pad was drilled and then X-rayed to check for registration. If the coupon was not centered, the board was remounted, the drill alignment adjusted, a hole drilled in another coupon, X-rayed again, and the sequence repeated until the drill was properly aligned. When a hole was centered, the board was drilled on the circuit pads, the connector pads, and the connector mounting pads.

Before copper plating, the holes needed to be cleaned. The board was rubbed gently with wet sandpaper to remove protruding copper caused by the drilling operation. It was then baked and immediately plasma desmeared to remove any acrylic adhesive inside the holes caused by the drilling operation. The plasma desmearing unit is shown in Figure 8.

The board was next electroless and electrolytically copper plated using standard procedures. The procedure for imaging the outer layer circuit patterns was the same as for imaging the inner layers. The board was scrubbed

FIGURE 8. PLASMA DESMEARING OPERATION

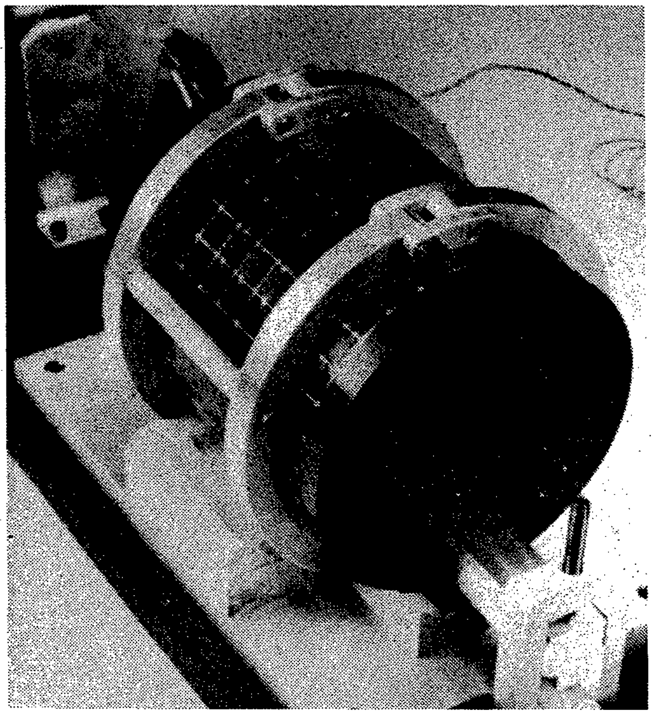


FIGURE 9. CYLINDRICAL CIRCUIT BOARD IN BONDING

to remove oxidation, placed in an oven, laminated with dry film photoresist, aligned with the proper negatives, exposed to ultraviolet light, developed, touched up, etched, stripped, and scrubbed.

After trimming the printed circuit board to its finished part dimensions, it was ready to be bonded into a cylindrical shape. A strip of cast acrylic adhesive material was cut out. The bonding surfaces of the circuit board were cleaned with alcohol and the ends were not touched after being cleaned. A soldering iron with a flat tip was used to tack the adhesive strip to the bonding end of the circuit board.

The circuit board needed guide holes punched into each bonding end for insertion into the bonding fixture. A fixture held the bonding end secure and a punch was run through each guide hole on the fixture to create these holes. After the holes were made, the circuit board was placed into the bonding fixture (Figure 9). Heat was applied along the bonding edge via a heater element to complete the bonding cycle. The temperature was monitored and controlled by a temperature controller box. When the bonding was complete and the circuit board cooled down, it was removed from the bonding fixture. The board was then ready to have its connector installed and to be continuity checked.

The connector was installed and its pins were soldered to the board, then the solder points were cleaned with alcohol to remove any flux remaining on the pins. A continuity test box was hooked up to the connector. A switch on the test box allowed the user to select any one of the eight layers for testing. A probe connected to the test box allowed the user to touch any desired point on the circuit board, and if the continuity was good a light on the test box illuminated. If the board had good continuity it was ready to have components placed into it.

Several different types of multilead components and resistors were installed (Figure 10). The components were inserted on the interior of the circuit board so that their pins would extend through the board to the exterior for easy placement of solder paste on each pin. It took about five hours to place all of the components onto the circuit board.

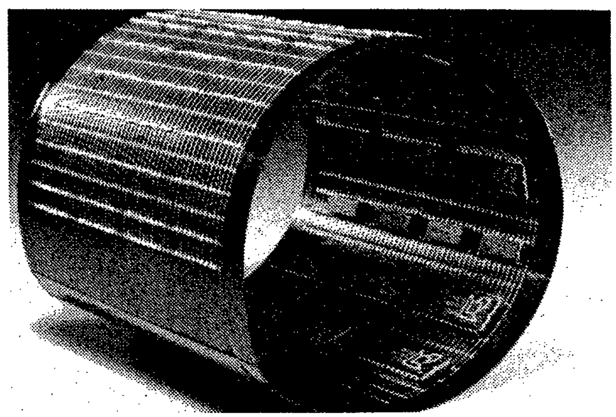


FIGURE 10. CYLINDRICAL CIRCUIT BOARD WITH MULTI-LEAD COMPONENTS

A turbocharger air compressor that applied a preset air pressure to a syringe filled with solder paste was used to place the solder paste onto each component lead. It took about two hours to coat fourteen hundred component leads with solder paste.

The circuit board was placed into a fixture that prevented the board from deforming when it was placed into a vacuum temperature box to remove any absorbed water from the polyimide material. The vapor phase solder machine (Figure 11) performed the soldering in one minute, fifteen seconds. The machine had three steps. First, the basket containing the circuit board in its fixture was lowered to a preheating stage so thermal shock would

FIGURE 11. VAPOR PHASE SOLDER MACHINE

not occur. Second, the basket was lowered into the soldering vapor, then pulled up to the preheat stage to allow the vapor to condense and go back into the vapor solder chamber. The basket was pulled back up to its stowed position and when the circuit board had cooled down the board was removed from the basket and holding fixture.

The board with components installed was placed into a cleaning tank to remove the solder flux and any other contamination. This completed the cylindrical circuit board fabrication.

References

(1) Final Report for Contract DAAH01-76-C-1100, "Semi-Additive Processes for the Fabrication of Printed Wiring Boards", Hughes Aircraft Corp., Fullerton, CA, for MICOM, 1978.

(2) L. R. Volpe, "Metriform Fabrication Spurs Development of High Density Circuits", Electronic Packaging and Production, May 1981.

(3) Final Report for Contract DAAH01-81-C-A777, "Manufacturing Methods and Technology for Non-Planar Printed Circuit Boards", General Dynamics Pomona Division, Pomona, CA, for MICOM, 1983.

Brief Status Reports

Project 6098. Production of Special Armor Steel. Steel plate from 3/16 to 2 in has been successfully rolled to the desired texture. Some problems with flatness still exist to be resolved. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6079-01. Monocrystal Alloy for High Pressure Turbine Blades. Monocrystal application analysis has been initiated for cooling air trade off, property verification and stress analysis. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6107-02. Adaptive Fluidic Damper. The manufacturing process, alternate materials and an economic analysis have been completed. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6107-03. Organic Composite Road Wheel. A composite roadwheel was designed using glass and graphite fibers in an epoxy matrix. The current aluminum roadwheel design is being compared to the composite wheel to determine adequacy. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6121. CAD/CAM for the Bradley Fighting Vehicle. Program budgets and schedules completed. Procurement of a robotic system has been initiated. AT-ARC hardware and software compatibility has been completed. Vision subsystem procurement has been initiated. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 3592. Improved Graphite Reinforcement. Temperature and line speed were varied to optimize the graphitization step. Best strength and modulus values were found. The contractor is preparing the final technical report after providing 20 pounds of fiber. For more information, contact Richard Green, TROSCOM, (314) 263-3353.

Project 3083. MM Wave Communications Front End Module (CFEM). Microwave associates designed the mixer. IF amplifier, detector, isolator and voltage controlled oscillator for the millimeter wave command post radio. A lock-on module is being considered. Design of the pin diode attenuator, coupler and filter continued. For more information, contact Al Feddeler, CECOM, (201) 535-4926.

Project 5005. Computer Aided Design for Cold Forged Gears (Phase I). The computer program, Geardi, developed in this phase corrected tool geometry for elastic deformation, modify geometry for temperature differentials, and computer wire electrical discharge machining paths for manufacturing both the die and punch. A spur gear, Eaton part number 27952, and a helical gear, Eaton part number 49221, were approved for forging. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5067. Plastic Battery Box. Modifications to battery box lid are being made by contractor. This is necessary to comply with multi-temperature stress test. This additional testing was requested by DRSTA-G for the 5-ton vehicle. Test results may affect TDP. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5075. Military Elastomers for Track Vehicles. Procurement actions and testing arrangements are being made for T156 (Abrams M1) track shoes. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5082. Flex Machining System (FMS Pilot Line or TLV Comps (CAM) (Phase V). Suspension components manufacturer was provided. This effort included modeling batch mode operations, alternate production strategies and capacity. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5083. Upscaling of Advanced Powdered Metallurgy Processes (Phase 3). The dies for the M2/M3 gear have been designed by the interactive computer program. The funds from this project have been utilized to monitor another Phase 4 project. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5090. Improved and Cost Effective Machining Technology (Phase V). Contractor has selected 5 of 6 candidate components which will be used to show feasibility of non-traditional machining processes application. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6054. Advanced Metrology Systems Integration (Phase II). All Task for Phase I have been completed, and the guidelines for future IMS have been established. However, the simulation model computer software program requires modification, since it is not compatible with TACOMs prime computer system. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6059-13. Metal ARC Spraying. Investigation of processes and process specification development are complete. Preliminary process evaluation has been initiated. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6059-17. Pre-Paint Cleaning System. Literature survey has been conducted and project coordination has been established with BRADC. Test specification has been established. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6059-19. Squeeze Cast Road Wheels. A turret hatch has been designed suitable for the squeeze casting process. Specification evaluation has been initiated. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6079-02. Rapidly Solidified Rate (RSR) Nickel-Base Superalloy. Under components qualification, component inspection and evaluation has been started. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6079-06. Automatic Deburring of Engine Components. Review of the state-of-the-art of automated deburring units has been completed. A robotic deburring approach has been selected. Avco Lycoming is currently selecting the robotic unit. Requirements are to deburr as many components as practicable. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6090. Tooele Army Depot Productivity Improvement Program. The majority of the preparatory work for the depot program has been completed. The project is now awaiting further funding enabling Phase I to begin. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6095-03. Surface Treatment and Cast Hardening of Steel Components. Effort to date has been CAD geometric modelling of coil design for candidate gears. Coils, tooling, and test gears are being procured. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 3115-34. Improved On-Site Service. Air speed calculations produced from the output of a differential pressure transducer passed through a voltage to frequency converter, counter, and microprocessor have been completed. This software has been committed to EPROM for use. Procurement has started on air speed modifications. A quantity of differential pressure transducers is being purchased. Portions of the hydraulic pressure standard work has been completed. Evaluation of the pressure transducers is underway. For more information, contact K. Magnant, TMDE, (205) 876-2891.

Project 6099. Manufacturing Methods for Specialized Armor Materials. AMMRC, AMCCOM, and PBM have progressed in the areas of materials, processes and facilities toward realizing the program objective. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6107-01. Computer Manufacturing From High Strong Lightweight Ferrous, Non-Ferrous and Material Matrix. Two contracts were awarded. One has completed the DIN design, which consists of DWAL20 tubes with a steel jacket. The other has completed the casting design for the pins and is modifying the loom for weaving the silicon carbide fibers. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 3115-17. Dynamic Electrical Measurement Standards. A modular pulse circuit has been evaluated. The circuit promises to be very versatile since it can be pulse operated, continuously modulated, or operated in a static forward biased mode. For more information, contact K. Magnant, TMDE, (205) 876-2891, F. Seeley, TMDE, (205) 876-2666, or L. Bowling, TMDE, (205) 876-8417.

Project 3115-25. Basic Metrology Standard for Use in Wide-Ranging Environments. Additional wiring has been installed so that voltage of references placed in an environmental chamber may be monitored. This will be used to measure the response of the reference to varying temperature and humidity conditions. Characterization of various commercial solid state voltage references devices continued using the automated system. It has been concluded from measurements made thus far that a filter on the output is required in order to achieve dependable results. For more information, contact K. Magnant, TMDE, (205) 876-2891, F. Seeley, TMDE, (205) 876-2666, or L. Bowling, TMDE (205) 876-8417.

Project 5052. Army Engineering Design Handbook for Production Support. Continued work on 706-158 and 159, dynamics of ballistic impact, parts I & II, and 706-199, development guide for reliability, part 5, contracting for reliability.

Project 4005. Water Jet Material Removal System Phase II. The system has been fabricated and delivered to RRAD. One of the pump motors was found to be defective. The motor was replaced by the contractor and acceptance tests will be performed.

Project 4005. Water Jet Material Removal System Phase II. The system has been fabricated and delivered to RRAD. One of the pump motors was found to be defective. The motor was replaced by the contractor and acceptance tests will be performed. For more information, contact Mike Ahearn, DESCOM, (717) 263-6591.

Project 3115-19. Submillimeter Wave Standards. This task has been completed. This system is now qualified as a measurement system for use in certifying standards for Army primary calibration laboratories. For more information, contact K. Magnant, TMDE, (205) 876-2891, F. Seeley, TMDE, (205) 876-2666, or L. Bowling, TMDE, (205) 876-8417.

Project 3115-01. Josephson Effect Voltage Standard. A one PPM voltage standard was delivered. Problems were encountered during initial operation of the system. Liquid nitrogen used to precool the Dewar solidified at the bottom of Dewar preventing insertion of the Josephson junction probe. Testing of IPPM voltage standards continued during this reporting period. Problems still exist in the production and selection of appropriate Josephson-junction devices. The problems are peculiar to individual devices and may cause non-vertical steps. For more information, contact K. Magnant, TMDE, (205) 876-2891.

Project 2642. Advanced Penetrating Radiation Technology for Product Evaluation. Speed and sensitivity of low silver films have been compared with conventional industrial radiographic film. Exposed curves are being evaluated for the films. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 3411. Non-Planar Printed Circuit Boards. All work has been completed and a final status report has been received. Multilayer cylindrical circuit boards and a microwave dish antenna were used as samples for developing the manufacturing processes. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5024. Gear Die Design and Manufacturing Utilizing Computer Technology (CAM). The movie on CAD/CAM of spiral bevel gears has been approved. A 16.5 inch spiral bevel gear has been selected for forging. The spiral bevel gear program, SPBEVL, was executed to predict settings to produce the EDM electrodes to cut the forging dies. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5053. Fabrication Techniques for Hi Strength Structural Ceramics. AMMRC has initiated efforts to hot press composites of SI3N4 and varying layers of ZR02 cloth. Adiabatic diesel engine components (Phase II). Contractor has initiated efforts to optimize material and manufacturing technologies. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5054. Laser Surface Hardened Combat Vehicle Components. Pilot heat treating of test samples is complete. Samples have been delivered to TACOM for evaluation and marking. Laboratory testing is complete. Field testing has been initiated. Laser heat treating of hardware is complete. Hardware testing is complete. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 4575. Laser Welding Techniques for Military Vehicles. Contract awarded. Currently addressing porosity problem through deoxidants and beam oscillation. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 3094. Communications Technology Techmod for JTIDS. Collins developed preliminary specs for a work cell for placing surface mounted components on printed circuit boards. Also wrote a spec for data and distribution system. For more information, contact Al Feddeler, CECOM, (201) 535-4926.

Project 1051. Replacement of Asbestos in Rocket Motor Insulations. Kevlar filled propellant grain inhibitors proved to be equal to asbestos filled inhibitors. Kevlar filled smokeless insulators were tested and are being analyzed. Work is leading to the test phase in the other work. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1060. Electrical Test and Screening of Chips. The machine structure and architecture is so devised as to allow implementation as a stand alone or a host operated system. The internal controllers are partitioned into logical work stations. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1086. Cobalt Replacement in Maraging Steel-Rocket Motor Components. Scale up to 14 inch diameter and concept demonstration have been started. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1089. Integral Rocket Motor Composite Attachments. The contract was awarded to Hercules Inc., Bacchus Works, Magna, Utah. Structural requirements determination, component selection, and static/dynamic analysis have been completed. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1121. Missile Manufacturing Productivity Improvement Program. A scope of work was prepared and contract documents are in the approval chain. Meetings have been held with Navy and Air Force. Martin Marietta will study its plant and determine what MMT and business system must be implemented for hellfire production. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3263. Printed Wiring Boards Utilizing Leadless Components. Hughes optimized methods for attaching leadless chip carriers (LCC) to printed circuit boards. Tasks were pretinning, soldering, bonding, conformal coating, and testing. All work is completed. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3376. Testing of Electro-Optical Components and Subsystems. All technical work has been completed. Final technical report draft has been received and approved. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5071-71. Improved Copper Crusher Pressure Gages. The internal ballistics division completed its analysis of the gage parameters using finite elements and prepared a gage design. The design was modified by mtd to fully satisfy known requirements. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 5071-76. Gamma Dosimetry Improvement and Modernization Program. The basic production gamma dosimeter was changed to a calcium fluoride chip from lithium fluoride powder. An automated gamma dosimetry data base program for data storage and retrieval and report preparation has been completed. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 5071-01. Acceptance Test Procedures. The central library for the total ATP program (ammunition, armor plate and weapons) was maintained. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 5071-43. Test Automation. This subtask identified procedures/ equipments needed to automate existing RF simulators and RF monitors. Results are reported in JPL report (JPL D1052), October 83, subject DVAL/GPRS Automation and integration. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 5071-57. General Purpose Bit Slice Microcomputer. This project has provided knowledge in bit-slice hardware technology, microprogramming, and minicomputer interface applications. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 2962. Automation of 65 Degree C Propellant Surveillance Test. A Textronix computer with display terminal, together with essential peripherals such as a graphics copier were produced. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2968. Investigation of Scan Photoacoustic Microscopy For Ceramics Inspection. A statement of work has been prepared for the demonstration of the scanning photoacoustic microscope (SPAM) for detection of surface and near surface defects in structural ceramic material. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2972. Capillary Gas Chromatographic Test of Army Solid Propellants. The results of this effort have demonstrated that the capillary gas chromatography is a significant improvement over packed column gas chromatography. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2980. Portability of Test Software for VHSIC Chips. The contract was awarded. Work has started on reviewing the VHSIC chip and test software specifications to determine commonalities. ATLAS, PASCAL and ADA languages were reviewed for suitability as common intermediate test description language. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2981. Fluidic Power Supply Acceptance Tester. The high pressure acceptance tester breadboard work has been completed. All of the purchased components have been received. The computer has been integrated with the prototype pneumatic system. The trajectory data software is complete. For more information, contact John GAssner, AMMRC, (617) 923-5521.

Project 3001. New Acceptance Tests For Chemical Agent Resist of Urethane Paints. A contract for the conduct of this effort was awarded. A literature search is underway by the contractor and techniques to prepare thin films evaluated. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 3006. Acoustic Emission Monitor/Control of Gun Tube Straightening. The gun tube bend tests were completed. Investigated the benefits of using noise analysis equipment. Performed on-line, full-scale testing. Established AE parameters to be applied to production cannon tubes. Completed the full scale testing. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 3010. Digital Image Amplification X-Ray System. Two inert standard were designed and fabricated. Multiple X-rays were taken and analyzed to determine the defects within the inert fillers. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 5064. Light Weight Saddle Tank (Phase III). Leak development at return line which has delayed testing at APG. New tests were requested by potential users prior to their implementation. New testing to satisfy federal motor safety regulations continue. Potential users who would implement project results are the interested parties. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5067. Plastic Battery Box. Modifications to battery box lid are being made by contractor. This is necessary to comply with multi-temperature stress test. This additional testing was requested by DRSTA-G for the 5-ton vehicle. Test results may affect TDP. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 7465. Advanced Composite Sensor Support Structure (ACS-3). Contract was awarded to McDonnell Douglas Astronautics Company. A critical design review will release work on tooling fabrication. For information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 3068. Increase Productivity of Varactors and Pin Diodes. Co-planar contact-side via-hole GAAS varactor chip design is abandoned. Process now incorporates thermal epitaxy and ion implant. Deep level trap. Measurement equipment is set up. Problems with the oxide/nitride passivation process still exist. For more information, contact Al Feddeler, CECOM, (201) 535-4926.

Project 3073. Tactical Graphics Display Panel. GTE resolved high line resistance and shorting problems for 10x12 in. thin film electroluminescent display panels. Brightness achieved is between 60 to 100 footlamberts. Exerciser was completed and demonstrated on a CRT. New insulator will be tried. For more information, contact Al Feddeler, CECOM, (201) 535-4926.

Project 2611. Sorption of Agents on ASC Whetlerite. Adsorption isotherms were determined for ASC whetlerite charcoal at four levels of impregnation, for a production lot of impregnated charcoal, and for a standard charcoal of known surface area using two independent methods. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 7412. Infrared Detector for Laser Warning Receiver. Perkin-Elmer Corporation made 86 indium arsenide IR detectors. Processes include diffusion of zinc-diarsenide, lapping and plating wafer backside, chrome-gold plating of frontside, masking, etching an interdigitated pattern, and mounting and wiring to header. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7415. MMT T700 Blisk Repair. Two welding operations have been defined for this repair program, plasma and TIG. Coupons for high cycle fatigue and corrosion tests have been fabricated. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7427. Attack Helicopter Productivity Improvement (API) Program. Booz Allen and Hamilton hired by Hughes as a consultant. A top-down analysis is in process. Existing cost, schedule and quality drivers analysis was completed. An assessment and identification studies are in process. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7433. MMT—IPI PGM—Bell Helicopter, Inc.—AHIP. Phase I work is complete. Ten major thrust areas were identified. The as-is writeups have been completed and the to-be items are being reviewed by the Bell upper management. Six initial projects are being conducted on the EA model. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 2894. Residual Stress Determination by Acoustic Wave Velocity. Evaluated the ultrasonic interferometer. The interferometer will be used for determining the third order elastic constants under applied stress conditions which are required for residual stress determinations. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 7298. High Temperature Vacuum Carburizing. Modification to the AISI gear steel vacuum carburizing has been completed. Components have been remanufactured, heat treated and shipped to Boeing-Vertol for evaluation. Metallurgical evaluation of all the specimens is still on-going. For more information contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7371. Integrated Blade Inspection System (IBIS). Completed the work on the IRIM flaw and airfoil section including the performance and validation test plans. IRIM hardware including high speed image acquisition and manipulation equipment was acquired. For more information, contact Fred Reed, (314) 263-3079.

Project 7382. Low-Cost Composite Main Rotor Blade for the UH-60A. A new, improved, single piece mandrel was evaluated and found to reduce manpower time. Fabrication of full sized blades, Phase 2, was initiated. Work was conducted in-house and consisted of fatigue tests on a ballistically damaged blade section and extensive negotiations with the contractor. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7389. Production of Aluminum Airframe Comp (Superplastic Forming). Detail design refinement and tool design is completed. Tools are fabricated and proven. Drawings are released. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 2834. Improved Track Pin Shot Peening Inspection. The implementation phase has been completed. It consisted of installation of automated X-ray diffraction equipment. During implementation, it was found necessary to design a new jig more suitable for production environment for holding track pins. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2895. NDT of Advanced Composite Structures for Bridging. A laboratory model of a hand scan ultrasonic c-scan system optimized for bridging application has been assembled. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2926. Testing of M55 Detenator Stability Sensitivity and Output. An automated system for testing M-55 detonators stab sensitivity and output was designed. Orders have been placed for the required equipment. Components which can not be purchased have been designed and fabrication has started. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2932. Assessment of Glare/Scatter in Fire Control Optical Systems. A survey of glare measurement techniques was undertaken. A number of techniques were identified and will be considered for this effort. Also, a visit was made to EAstman Kodak Corporation to discuss glare techniques used. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2934. Application of X-Ray TV System for Diffraction Patterns. Experiments were conducted to determine the optimum hardness threshold values. Standard vickers hardness measurements were made on flat and curved specimens and they compared favorably with those computed from the X-ray diffraction image. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Electronic Dynamometer Simulation

Power and Inertia Simulator Simplifies Testing

By George Taylor
U.S. Army Tank—Automotive Command

TACOM is funding an MM&T program aimed at equipping the Mainz Army Depot in West Germany, which rebuilds vehicles, with a computer-controlled dynamometer system that will for the first time electronically simulate vehicle inertia.

In dynamometer testing, a dynamometer measures an engine's mechanical power by generating electrical resistance against its rotation to simulate the load of a moving vehicle.

Though this kind of testing is effective, up until now it has had one shortcoming: with current test equipment it is possible to produce only a limited amount of inertia. This is done by mounting a heavy flywheel to the dynamometer which, when rotated, simulates the inertial load of a vehicle.

The problem with this approach is that it is not economically practical for simulating tanks and other heavy vehicles, because the flywheel's weight must equal the weight of a given vehicle to simulate its inertia.

Also, the weight and size of such a flywheel would cause unwanted oscillations in the test equipment that would be difficult to eliminate.

Thus, conventional dynamometers for the most part simulate only vehicle rolling resistance and do not produce the inertial forces that occur during other conditions such as uphill driving and braking.

More Practical Economically

The new dynamometer system, called the Power and Inertia Simulator (PAISI), can be tailored to simulate the inertial loads created by any vehicle, regardless of its weight.

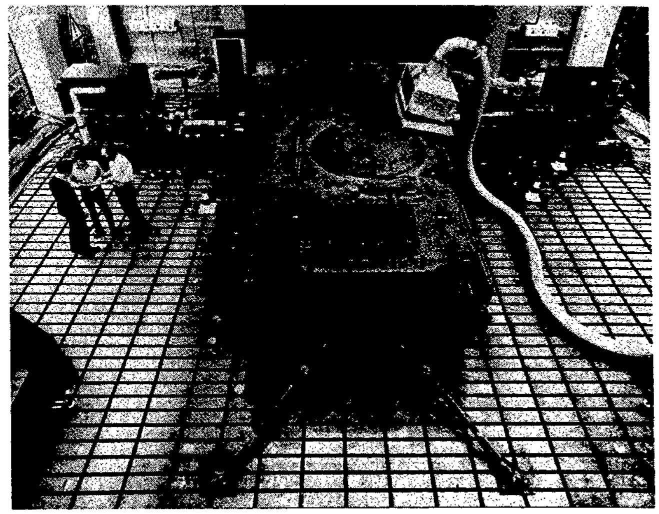
The PAISI was developed jointly by the West German-based Brown Boveri Corp. and the University of the German Armed Forces, in Hamburg.

It comes in a variety of test-rig versions. Each is designed to test either a specific type of major vehicle component or system—such as a transmission or a brake system—or a complete vehicle.

According to Donald Cargo, PAISI coordinator in TACOM's R&D Center, the version to be installed at Mainz is a tracked vehicle performance test rig.

"This system," he said, "not only simulates vehicle rolling resistance, but also the effects of mass inertia encountered while accelerating, coasting, braking, ascending and descending hills and turning."

The PAISI consists of a vehicle test stand—comprising two dynamometers and a 1,600-ton foundation that supports and stabilizes the test vehicle—and a computerized electronic control system.



BRADLEY HULL RIGGED FOR PAISI FEASIBILITY TESTS AT THE UNIVERSITY OF THE GERMAN ARMED FORCES, MAINZ, GERMANY

In operation, a test vehicle is first moved into position and clamped to the foundation. Technicians then remove the vehicle's tracks and couple one dynamometer to each track drive sprocket.

Throughout the ensuing test, an operator "drives" the vehicle. That is, he accelerates, shifts gears, steers and brakes the vehicle, while the electronic control system makes preprogrammed adjustments to the dynamometers' speed and torque output to simulate the various inertial effects.

The electronic controls can change the speed and torque of each dynamometer independently, thereby making it possible to simulate the inertial load of a tracked vehicle when turning.

Unlike a wheeled vehicle, which is steered by turning the front wheels in the desired direction, tracked vehicles use a method called pivot steering. In pivot steering, the driver makes a turn by increasing the speed of the track on one side of the vehicle while decreasing the track speed on the opposite side.

NOTE: This manufacturing technology project was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The TACOM Point of Contact for more information is Don Cargo, (313) 574-8709.

"Except for the bumping and jouncing that occur when passing over terrain, and a slope test required for brake tests and for detecting fuel leaks, the PAISI can subject a vehicle to everything it would experience on a real test track," Cargo asserted.

Cargo said that the PAISI will greatly expand the Mainz Army Depot's capacity to test rebuilt vehicles. He said its current capacity is severely limited because the facility's vehicle test track is too small to adequately test today's combat vehicles.

Noise Factor Reduced

Moreover, the track is situated in a residential neighborhood and can only be used during daylight hours.

"The PAISI will allow Mainz to meet its testing requirements and at the same time minimize its road requirements," Cargo said.

Noting other advantages over conventional test procedures, Cargo said, "The system will result in significant cost savings—both in terms of manpower and track wear. Furthermore, Mainz will be able to run the test stand 24 hours a day, with absolute security and without the problem of offending the neighborhood.

"Also," he added, "the tests will be totally objective. When vehicles are driven on a test track, the results are not objective, because they depend to some extent on external variables such as how the driver feels or what the weather is like. But with the PAISI, these external variables can be eliminated."

Installation of the Mainz tester is slated for completion in 1986. It will be capable of testing vehicles weighing up to 25 tons, including the M2/M3 Bradley vehicles.

Second Facility Likely

According to Cargo, if this first unit proves to be a success, a second PAISI is planned for Mainz that will be large enough to test vehicles with horsepower and weight greater than the current M1 Tank.

He said plans are under way to buy a highly sophisticated variant of the Mainz inertia simulator for TACOM's vehicle test cell in Building 212.

Said Cargo, "The TACOM system would give us the capability of taking every truck, tank and heavy equipment transporter and establishing base line operational characteristics for each. Then we would be able to objectively check random vehicles off a production line or rebuilt vehicles and compare their performance with these base-lines."

Cargo added that for new vehicle development, the proposed PAISI system would also be capable of testing and validating power train components—engines, transmissions, etc.—with inertia simulation for the anticipated weight of proposed future vehicles.

PAISI TEST OF GERMAN ARMY TANK AS SEEN FROM CONTROL ROOM

Stack Manufacture Unfeasible

TFT Display Design Complete

by

Robert Miller
U. S. Army Communications & Electronics Command

Multiple thin film layers of approximately 44 thicknesses were proven unfeasible for pilot line scale of production of integrated transistor displays by an MM&T project conducted by Aerojet ElectroSystems for the U.S. Army R&D Command. A major finding of this program was that the roughness of each surface is replicated and amplified as more layers are added. Control of this roughness will require more materials process research—material changes and tooling changes.

A thin film transistor electroluminescent display design meeting Army needs was completed. A pilot line was set up and demonstrated. The basic device was from four stacks: electroluminescent stack, counter electrode stack, thin film transistor stack, and addressing stack. Each of these stacks could be made on the pilot line and tested to confirm proper operation. However, all the stacks could not be built upon each other monolithically and operate properly.

It was concluded that the overall process is not sufficiently mature for a pilot plant operation. The unforeseen problems experienced on this program relating to surface morphology interaction render the present approach to making monolithic multiple thin film layers of this magnitude unfeasible without further research and development.

Pilot Line Effective in Principle

This article describes the results of the MM&T program to develop an electroluminescent display in which the addressing makes use of thin-film transistors at each pixel. The display was specifically designed to be made on a pilot production line using all additive processes. The pilot line was shown to be effective in principle since it did accomplish limited groups of processes well, though it would not accomplish the entire series of processes required to produce an electroluminescent panel with functioning thin-film electronic drivers. This major finding with the present process relates to the replication and amplification of nonuniformities through successive film layers.

In accordance with program guidelines, the displays were to have an overall size of less than 4 inches by 8 inches and contain a minimum of 77 rows by 222 columns that were matrix addressable for alphanumeric and graphic data. Additionally, the display was to have memory, and to be low in power, lightweight, rugged, and sunlight readable. (See Table 1)

NOTE: This manufacturing technology project that was conducted by Aerojet ElectroSystems was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The ERADCOM Point of Contact for more information is Bob Moore, (202) 394-3812.

During this program at AESC two pixel designs were completed and studied in detail. The first was fabricated as a pixel array of 38 rows by 49 columns on a 2.5 inch by 2.5 inch glass substrate as shown in Figure 1. Once perfected, the matrix was to be expanded to full size as shown in Figure 2. The expanded version would be made from four quadrants. A quadrant before edge trimming is shown in Figure 3. The second design was fabricated as a pixel array of 80 rows by 224 columns on a single 2.5 inch by 5 inch glass substrate. The array was made for 80 rows by 224 columns to allow for extra test rows and columns on the perimeter. An actual photograph of the electroluminescent display is shown in Figure 4. This design met all the geometric requirements of the ultimate device on a single substrate.

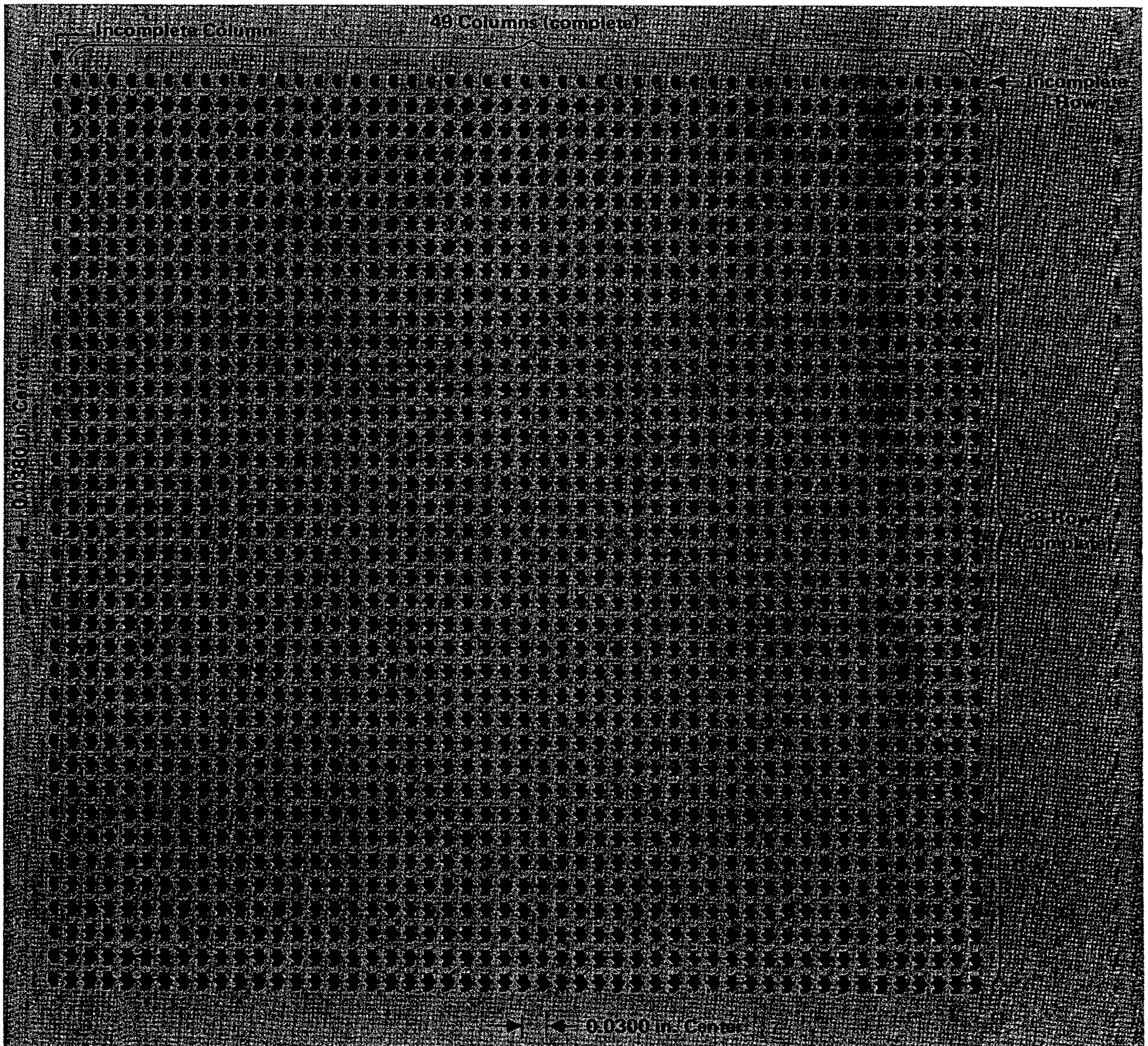


Figure 1

TFT Advantages	Application To EL	Application to LC and Other Nonemitters
Switch at Each Pixel	Not Needed, But Advantageous	Mandatory For Matrix Addressing
Memory	Advantage For 100% Duty Cycle	Mandatory For Matrix Addressing
High Voltage	Definite Advantage H. V. Line Driver Only Option	Not Needed At All
Large Area	No Advantage	Advantage Over MOS
Low Cost	Must Be Lower Than H. V. Line Drivers	Must Be Lower Than Optional MOS Switch

Table 1

Design Goals Revised

A third design was completed up through mask fabrication with a limited number of thin-film transistor stack fabrications. This design was set aside while detailed problems were being worked out on the first design. After the problems were resolved, it was concluded that a new design was justified, which led to the creation of the second design.

The lack of complete success was indeed frustrating for several reasons. As the films accumulated, the roughness would be multiplied until the size of the anomalies exceeded the thickness of the succeeding thin film. At this point the performance would become erratic. This was then compounded by the internal electric fields applied to the phosphors, semiconductors and dielectrics which were as high as 2MV/cm. Any pinholes at these field strengths would arc and destroy the entire film in the vicinity of the arc.

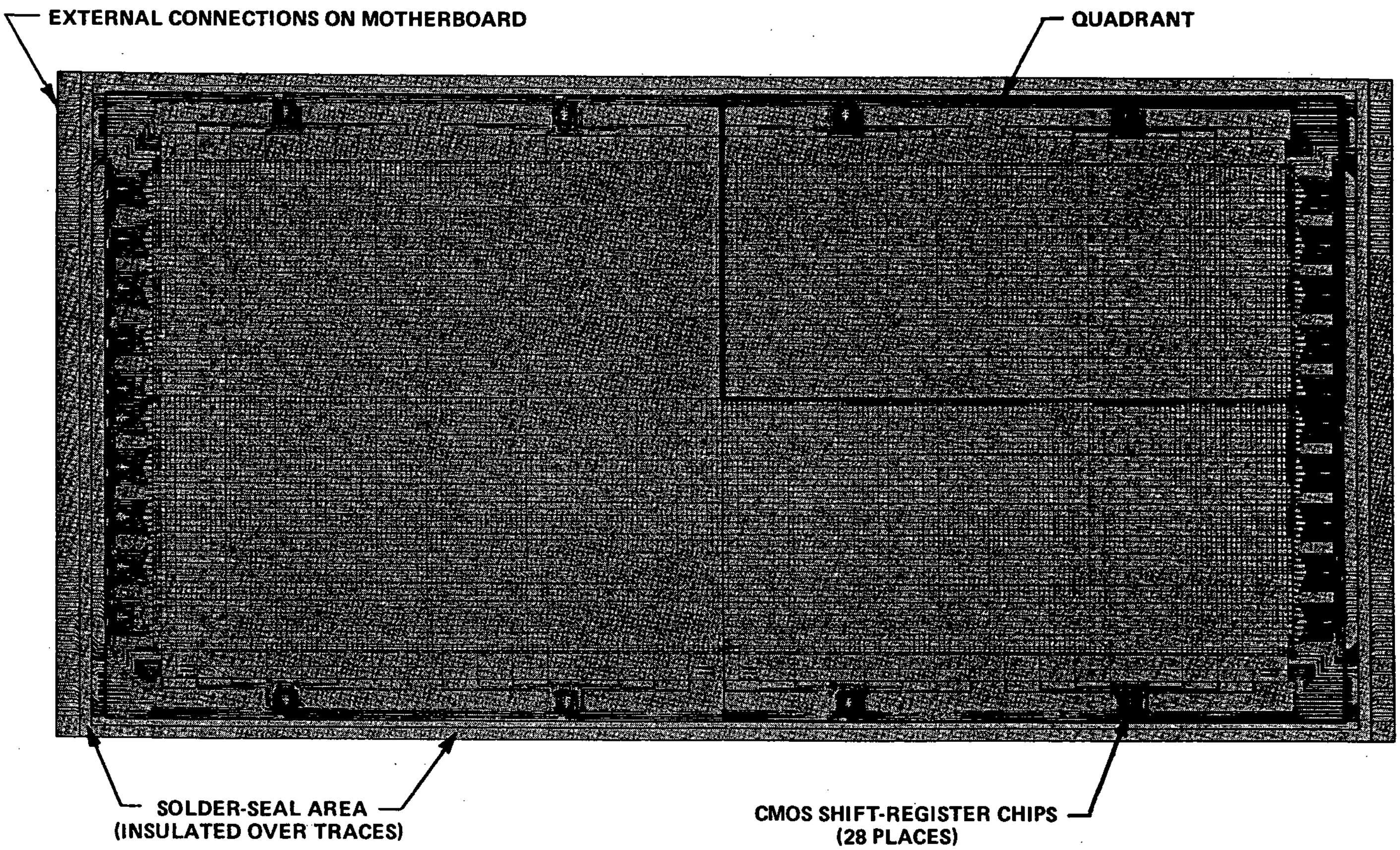


Figure 2

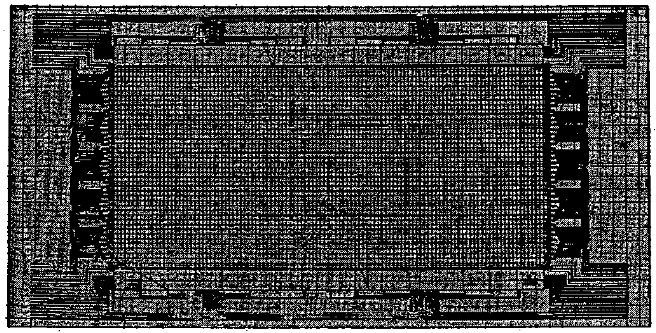


Figure 3

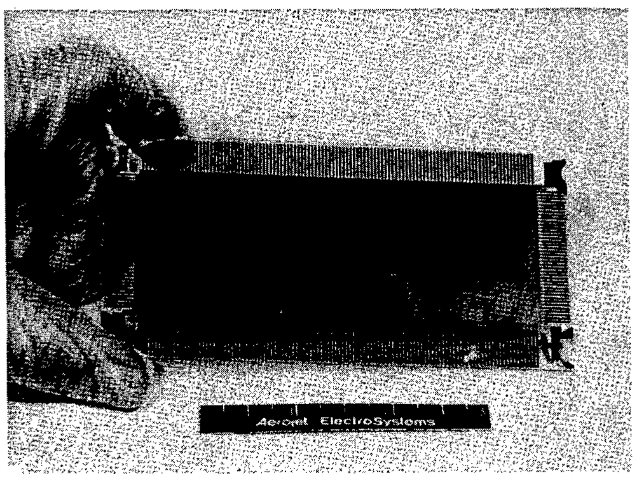


Figure 4

Thin Film Transistors

The thin-film transistor, invented in 1962 by Dr. P. K. Weimer at RCA, is a unique kind of transistor in that it can be made on a low-cost substrate such as a glass or polymer. As yet, however, there is no component in production using thin-film transistors, because of

- Successes in MOS FETs
- Technical problems in reproducibility
- Lack of a critical need heretofore.

A critical need now does exist in direct view flat-panel electronic displays. The successes in MOS have further accentuated the lack of low-cost low-power, lightweight flat-panel displays that are compatible with the new line of LSI microprocessors, memories, switching power supplies, etc. The technical problems with thin-film transistors are not significant for the flatpanel display application. The best approach is to keep the thin-film transistor circuits simple and the dimensions large.

Flat-Panel Displays Matrix Addressed

Flat-panel displays have a unique requirement in that they must be matrix addressed. Matrix addressing inherently produces "sneak" circuits, which cause at least one-third of the select voltage to be applied across all the nonaddressed pixels. Additionally, gas discharge and electroluminescent display technologies require a higher operating voltage than is readily available with MOS. Also, flat-panel displays can benefit from memory storage at each pixel. The memory allows for a 100 percent duty cycle. Without memory, the duty cycle and brightness are inversely proportional to the number of display array rows. The thin-film transistor circuit at each pixel eliminates sneak circuits, provides the necessary voltage gain to stimulate the display media, and facilitates the incorporation of memory elements.

Thin Film Transistor Stack

This transistor is more sophisticated than that developed by Dr. Weimer, in that it uses dual gates as shown in Figure 5. Dual gates provide sharper turn-off characteristics and a high β coefficient (geometric factor). The pixel circuit uses two thin-film transistors and a capacitor for display memory.

Fabrication techniques used are:

- Deposition of materials through chemically etched Kovar metal masks
- Ball-and-race aligned tooling set for mask and substrate registration
- Magnetic pulldown for mask clamping to substrate
- Tool and mask carousel for in-chamber interchange
- A three-chimney vapor vacuum-deposition chamber.

The thin-film transistor is a perfectly symmetrical electrical device if the source-to-gate geometry is identical to the drain-to-gate geometry. That is to say, the drain and source can be interchanged. The grounded electrode is the source. When the thin-film transistor is turned off by making the gate slightly negative, it has the electrical properties of a switch with low leakage.

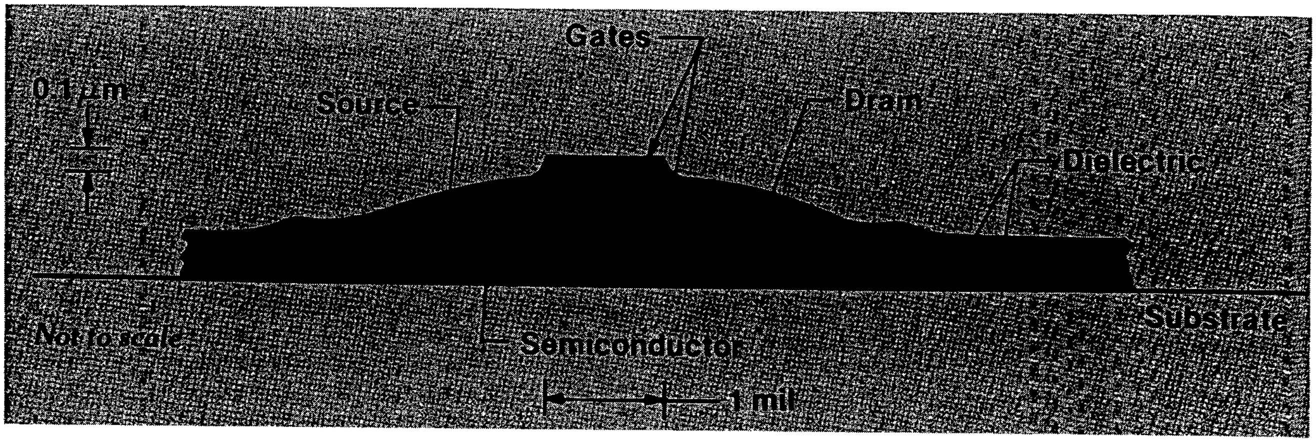


Figure 5

Counterelectrode Stack

The counterelectrode stack contains a capacitor used in series with the the electroluminescent capacitance for voltage division. It provides sufficient voltage drop that the pixel will not light. The second thin-film transistor shorts out the divider capacitor to turn on the pixel. When the divider capacitor is shorted out, the full voltage is applied across the electroluminescent thin film, which is electrically equivalent to a capacitor to a first approximation.

Electroluminescent Stack

The electroluminescent stack is built first on the substrate. The material is ZnS with Mn/Cu as the primary activator. The stack is optimized for steep brightness-to-applied-voltage performance. Brightness control is easily achieved with power frequency control.

A display with the electroluminescent performance is easily made sunlight readable. Since thin-film ZnS is transparent, the use of a black light-absorbing back layer or a reflecting back layer with front circular polarizer is applicable to achieve sunlight readibility.

Addressing Stack

The addressing stack contains the row and column lines and accommodates the crossovers. The row and column lines are extended to the edge of the glass substrate for external drive at MOS level voltages.

TFT-EL Display

The process profile for fabricating the display is outlined in Figure 6. Two basic approaches considered for connecting the thin-film transistors to the electroluminescent are monolithic and sandwich, as shown in Figure 7.

Electroluminescent display is the most efficient light emitting except for the cathodoluminescent techniques. The electroluminescent panel has a high imaginary power component which cannot be easily saved.

Design Problems Encountered

Design No. 1 had four major process problems:

(a) A hole had to be ion milled through the counter electrode stack and back filled with metal to connect the thin-film transistor with the electroluminescent pixel area electrode. This required a resist photolithographic step, an ion milling step, a metal deposition step and a resist removal step. The wet processing usually caused contamination of the substrate.

(b) A thick insulating film had to be used in the addressing stack to prevent capacitive coupling between row and column lines. It was hard to apply repeatedly and etch without causing contamination to the thin-film layers.

(c) The metal in-contact mask design did not allow for any error in alignment that may arise due to thermal expansion, wear, tooling variations, etc.

(d) The complete set of four stacks had too many thin film layers, which added to the morphology problem discussed above and reduced the yield probability.

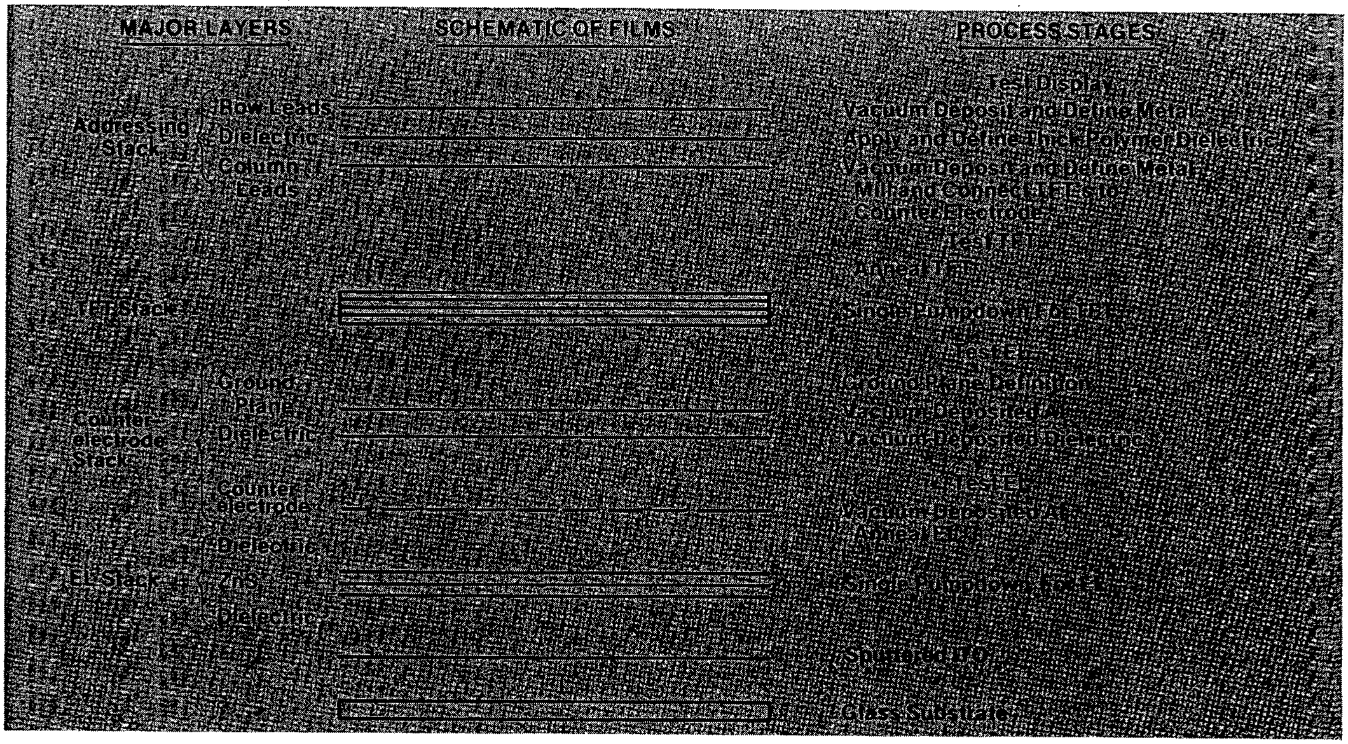


Figure 6

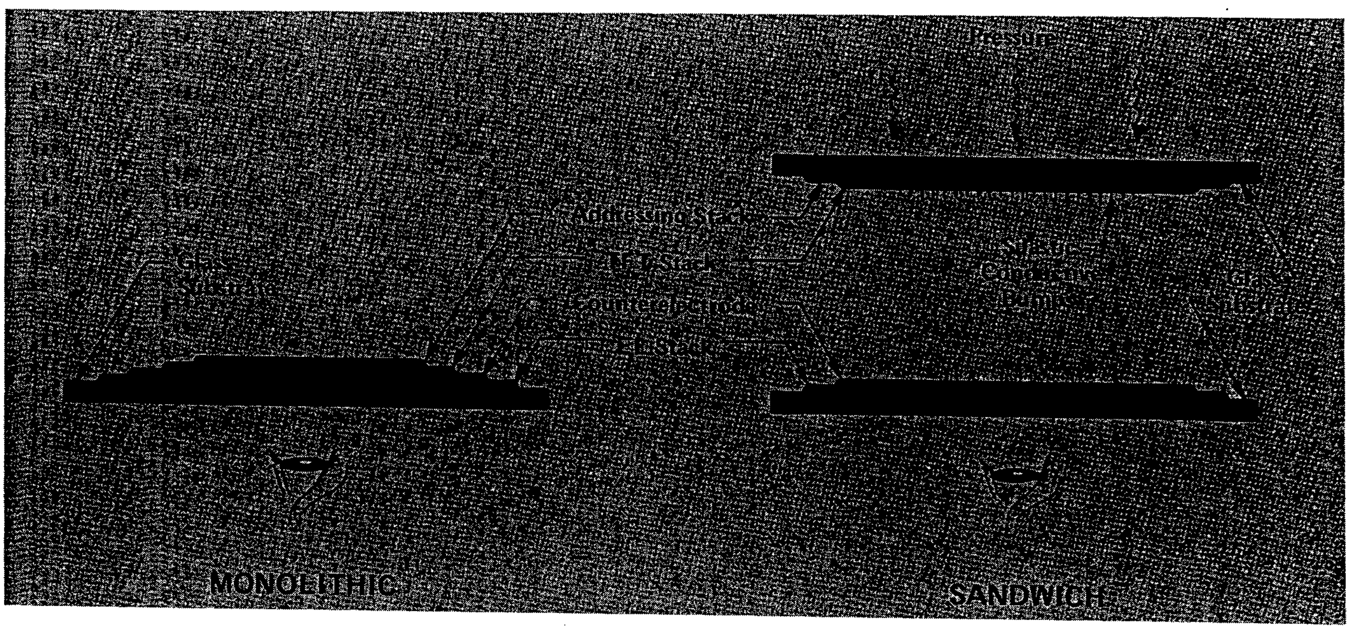


Figure 7

Design No. 2 More Effective

All the problems of Design No. 1 except (d) were eliminated in the redesign: (a) the stacks were made all additive. By using overlapping additive mask deposition the need to ion mill was eliminated. (b) All the layers were made additive including the addressing stack. The capacitive coupling was minimized through geometric design of overlapping areas. (c) An allowance of one mil of motion relative to all other masks was built into each mask during its design, except alignment between gate mask and source-drain mask. (d) The number of thin film layers was reduced, but not enough to completely eliminate the morphology problem.

The quadrant approach was abandoned. All the rows and columns needed were designed onto a single 2-1/2 in. x 5 in. substrate. This greatly simplified the overall assembly. The resolution was increased to approximately 50 lines per inch, which was considered quite acceptable for the Army applications.

PROBLEMS FOR PILOT SCALE PRODUCTION

Mask Alignment Heat Induced Error

The alignment of substrate to in-contact masks is difficult and sensitive to thermal changes.

Dielectrics are superior when deposited on substrates which are heated to 300 C or higher to avoid voids in the thin film columnar growth structure.

When heat is applied to a substrate approaching 300 C, large shifts occur in the pre-aligned metal mask position resulting in a significant misregistration of the pattern. Further, in order to provide radiant heating from quartz lamps, the magnetic clamping device which maintains intimate contact between the masks and substrate must be removed, resulting in potentially additional misregistration of the deposited pattern when reengaged. The magnets themselves lose magnetism at 300 C.

A compromise in heating for dielectric depositions was used. The alignment was preserved; however, the dielectric undoubtedly had more voids and the surface was undoubtedly rougher. The rougher surface was amplified up through each dielectric layer, contributing further to the ultimate weakness of the process.

Annealing

The thin-film transistors need to be annealed at 350 C for eight hours, or 400 C for three hours at a minimum. At either of these annealing profiles the preferred proprietary black layer would delaminate. Successful annealing could not be achieved at 300 C. This problem has not been resolved to date.

Conclusions

A final design was achieved which satisfied the program guidelines. A pilot line was set up which produced the display at an acceptable rate; however, the resulting displays did not operate satisfactorily.

A compounding of surface roughness through successive thin film depositions caused the final surfaces to be too rough to perform without breaking down electrically. This is one of the major findings of this program. Further reseach is necessary to eliminate the excessive roughness.

References

(1) Contract No. DAAB07-77-C-0583 between Aerojet ElectroSystems Company and U.S. Army.

(2) P. K. Weimer, "Handbook of Thin Film Technology", edited by L. I. Maissel and R. Glang (McGraw-Hill, New York, 1970), Chapt. 20.

(3) T. B. Brody and P. Malmberg, "Int. J. Hybr. Microelectron", 2.29 (1979).

(4) K. O. Fugate, "High Display Viewability: Thin-FIlm EL, Black Layer, and TFT Drive", IEEE Trans. ED. 24, No. 7 (July, 1977).

(5) Z. K. Kun, et. al., "Thin-FIlm Transistor Switching of Thin-Film Electroluminescent Display Elements", SID Proceedings, Vol. 21, No. 2 (1980).

(6) G. Kramer, "Thin-FIlm Transistor Switching Matrix for Flat Panel Displays", IEEE Trans. Ed. 22, 733 (1975).

(7) L. E. Tannas, Jr., "Fabrication and Application of Thin Film Transistors to Displays", symposium transactions for '80 ERADCOM Hybrid Microcircuit Symposium, Ft. Monmouth N.J., 4 June 1980.

(8) L. E. Tannas, Jr., "Matrix Addressing Flat-Panel Displays: IEDM Conference, Washington, D.C. 8-10 Dec. 1980.

(9) R. E. Coovert, et. al., "Feasibility of a Dual-Color ACTFEL Display", SID 82 Digest, May, 1982, p. 128.

(10) John Thornton, "High Rate Thick Film Growth," Academic Review of Material Sciences, Vol. 7, p. 239, 1977.

New System Faster

Cheaper Welds for the M1 System

By George Taylor
U.S. Army Tank—Automotive Command

A project involving TACOM and Avco Lycoming has led to the development of a laser welding system which the Army hopes will save some $3.5 million in production costs for a key M1-series tank engine component.

The project is part of a larger Department of Defense-wide effort called the Manufacturing Methods and Technology (MM&T) program.

The aim of this program is to improve the quality of military equipment and reduce its production costs whereever possible by applying the latest technological advances to develop improved manufacturing methods.

The M1's 1500 hp Avco Lycoming gas turbine engine uses a heat exchanger, commonly called a recuperator, that improves fuel economy by using exhaust-gas heat to preheat the incoming air before it enters the engine's combustion chamber.

This recuperator is a 22-inch-long unit consisting of 560 welded annular plates made of a nickel-based superalloy material. Each plate has an outside diameter of 27 inches, a 15-inch inside diameter, and is 0.008 inches thick.

The plates each have a pattern of ellipitcal- and triangular-shaped holes which serve as inlet and outlet air passages.

In assembling the unit, the plates are first welded in pairs around each of the holes. These plate pairs are then stacked on top of each other and alternately welded along their inside and outside edges.

The first 600 or so recuperators were assembled entirely with the standard resistance-welding method. In resistance welding, a high electric current passes from an electrode to the metal being welded. As the current flows through the metal, it encounters a considerable amount of resistance, which produces enough heat to fuse the metal.

But this approach proved to be expensive and time-consuming due to the complex nature of the welding. An alternate welding method was needed.

Laser Welding Introduced

So, late in 1982, following a three-year development effort that included both dynamometer and vehicle tests of laser-welded heat exchangers, Avco Lycoming began laser-welding the air passages—the most difficult part of the assembly operation.

In laser welding there are no electrodes. Instead, the metal is exposed to a high-energy laser beam which, in a matter of a few seconds, creates the intense heat needed to complete a weld joint.

The laser welder uses two 525-watt laser units, each having a computer-controlled moving mirror system that directs the laser beam to individual welding sites.

In addition, the machine has two work stations. Each includes a rotary positioning table and a fixture that are controlled by a robotic swing arm load/unload system shared between the laser stations. The welding units run out of phase, so that while one of them is welding the other is being loaded and unloaded.

Invisible Magic

"The only thing that touches the metal during the welding operation is the fixture that holds it in position," said David J. Pyrce, TACOM R&D Center engineer who heads the M1 recuperator welding project.

NOTE: This manufacturing technology project was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The TACOM Point of Contact for more information is Don Cargo, (313) 574-8709.

"To someone not familiar with lasers," he added, "it looks like the machine is welding by magic, because the laser beam is invisible to the naked eye."

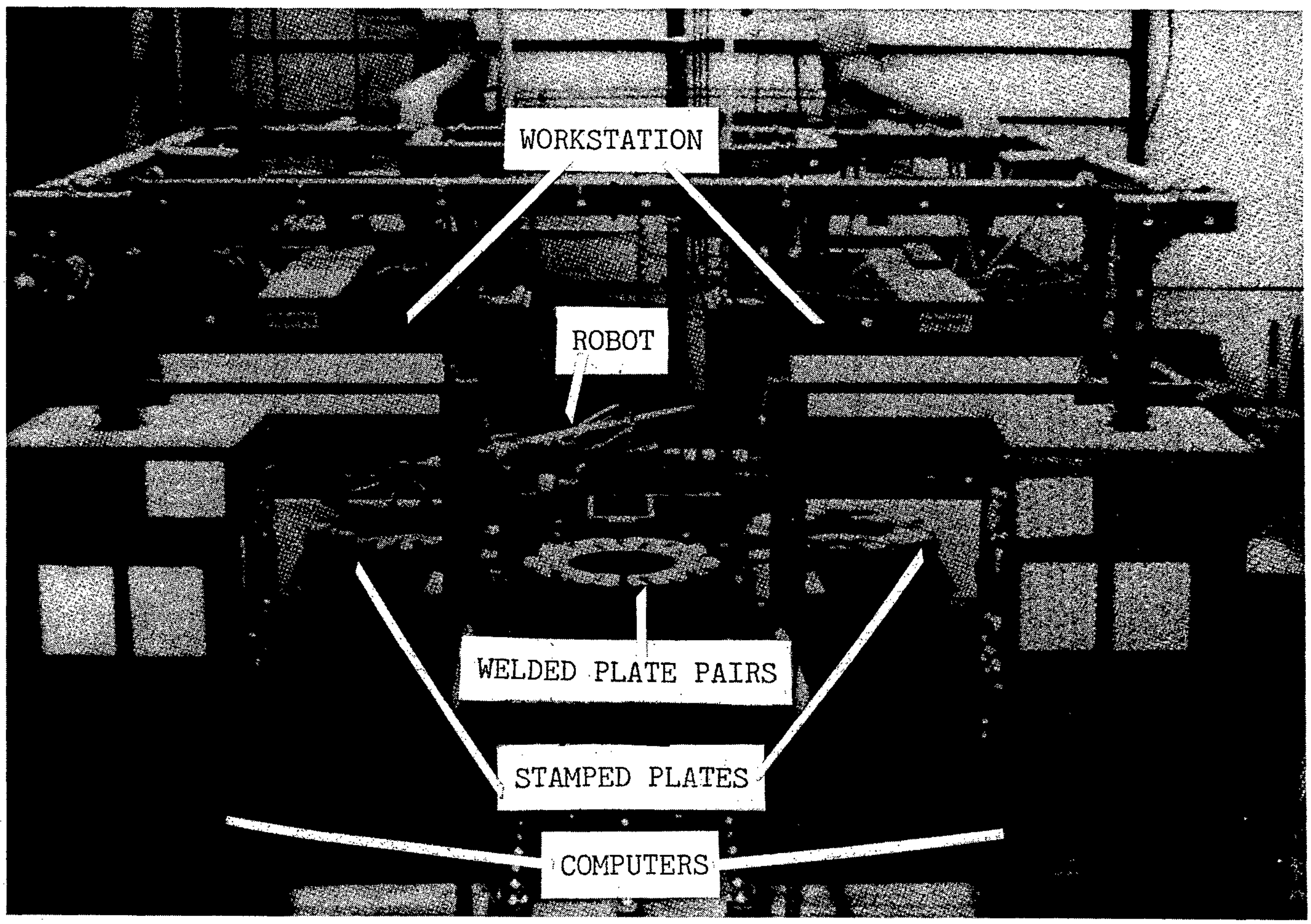
Noting advantages of the laser procedure over standard resistance welding, Pyrce said the new system welds at a rate of 90 inches per minute—nearly twice as fast as a conventional welder.

Less Labor Intensive

Additionally, he said production costs are less because the automated equipment makes the laser technique less labor-intensive. "It takes only one man to operate it, while the resistance welder requires three men," he said.

When asked if laser welding has other potential military vehicle applications, Pyrce said, "We hope someday to begin doing the remaining welds at the inner and outer edges of the heat exchanger plates with the laser.

"Also," he continued, "we have another MM&T project under way to investigate the possibility of laser-welding vehicle armor. We see a great potential here—particularly for welding the long, flat joints in vehicle hull floors and sides, where warpage during arc welding currently causes a lot of problems."



LASER WELDING SYSTEM FOR THE AGT-1500 TURBINE RECUPERATOR